TABLE OF CONTENTS

Section **Page**

1.0 INTRODUCTION 1-1
1.1 Hopi Regulatory Framework 1-2
1.2 Project Scope 1-3
1.3 Report Organization 1-4

2.0 TECHNICAL APPROACH 2-1
2.1 Public Water System Inventory 2-1
2.2 Source Water Delineation 2-1
2.3 Contamination Source Inventory 2-5
2.4 Susceptibility Analysis 2-7

3.0 PUBLIC INFRASTRUCTURE 3-1
3.1 Land Use Patterns 3-1
3.2 Public Water Systems 3-1
3.3 Support Infrastructure 3-3

4.0 HYDROLOGIC SETTING 4-1
4.1 Climate and Surface Water Drainage 4-1
4.2 Geology 4-1
4.3 Groundwater Occurence 4-3

5.0 SPIDER MOUND AND FIRST MESA SOURCE WATER ASSESSMENTS 5-1
5.1 Spider Mound (Yu Weh Loo Pahki) 5-1
5.2 Keams Canyon 5-5
5.3 Hopi High School 5-9
5.4 Polacca/First Mesa Consolidated Villages 5-12

6.0 SECOND MESA SOURCE WATER ASSESSMENTS 6-1
6.1 Lower Sipaulovi 6-1
6.2 Second Mesa Day School 6-4
6.3 Sipaulovi-Mishongnovi 6-8
6.4 Shungopavi 6-11
6.5 Hopi Cultural Center 6-15
6.6 Hopi Veterans Center 6-18

7.0 THIRD MESA SOURCE WATER ASSESSMENTS 7-1
7.1 Kykotsmovi 7-1
7.2 Bacavi 7-5
7.3 Hotevilla 7-8
7.4 Hotevilla Day School 7-12

8.0 MOENKOPI SOURCE WATER ASSESSMENTS 8-1
8.1 Upper Village of Moenkopi 8-1
8.2 Lower Village of Moencopi 8-4

9.0 SUMMARY AND RECOMMENDATIONS 9-1
9.1 Source Water Assessment Summary 9-1
9.2 Source Water Protection Measures 9-2

10.0 REFERENCES 10-1

ED_005149_00040842-00001

List of Figures

Figure

1-1 Location Map
3-1 Hopi Public Water Systems
4-1 Surface Geology of Black Mesa Area, Northeastern Arizona
4-2 Rock Formations and Hydrogeologic Units of Black Mesa Area, Northeastern Arizona
5-1 Spider Mound Topographic Base with Administrative Protection Zones
5-2 Spider Mound Aerial Base with Modeled Capture Zones and PSOC
5-3 First Mesa Area PWS Layout
5-4 Keams Canyon/Hopi High School Topographic Base with Administrative Protection Zones
5-5 Keams Canyon Aerial Base with Modeled Capture Zones and PSOC
5-6 Hopi High School Aerial Base with Modeled Capture Zones and PSOC
5-7 Polacca Topographic Base with Administrative Protection Zones
5-8 Polacca Aerial Base with Well No.5 Modeled Capture Zone and PSOC
5-9 Polacca Aerial Base with Well No.8 Modeled Capture Zone and PSOC
6-1 Second Mesa Area PWS Layout
6-2 Second Mesa Topographic Base with Administrative Protection Zones
6-3 Lower Sipaulovi and Second Mesa Day School Aerial Base with Modeled Capture Zones and PSOC
6-4 Upper Mishongnovi and Sipaulovi Aerial Base with Modeled Capture Zone and PSOC
6-5 Shungopavi Aerial Base with Modeled Capture Zone and PSOC
6-6 Second Mesa Area (West Side) Topographic Base with Administrative Protection Zones
6-7 Hopi Cultural Center Aerial Base with Modeled Capture Zone and PSOC
6-8 Hopi Veterans Memorial Center Aerial Base with Modeled Capture Zone and PSOC
7-1 Third Mesa Area PWS Layout
7-2 Kykotsmovi Topographic Base with Administrative Protection Zones
7-3 Kykotsmovi Aerial Base with Modeled Capture Zone and PSOC
7-4 Hotevilla and Bacavi Topographic Base with Administrative Protection Zones
7-5 Hotevilla and Bacavi Aerial Base with Modeled Capture Zone and PSOC
8-1 Moenkopi PWS Layout
8-2 Moenkopi Topographic Base with Administrative Protection Zones
8-3 Moenkopi Aerial Base with Modeled Capture Zone and PSOC

ED_005149_00040842-00002

List of Tables

Table

1-1 Regulatory Programs Supporting Source Water Protection Efforts
1-2 Alignment of Geographic Areas, Public Water Systems
3-1 Public Water System Administration
3-2 Public Water System Components
3-3 Supply Well Inventory and Reported Aquifer Characteristics
5-1 Potential Source of Contamination Inventory, Spider Mound and First Mesa Areas
5-2 MCL Exceedance Summary, Spider Mound and First Mesa Areas
5-3 EPA Violation Summary, Spider Mound and First Mesa Areas
5-4 Source Water Susceptibility Analysis, Spider Mound and First Mesa Areas
6-1 Potential Source of Contamination Inventory, Second Mesa Area
6-2 MCL Exceedance Summary, Second Mesa Area
6-3 EPA Violation Summary, Second Mesa Area
6-4 Source Water Susceptibility Analysis, Second Mesa Area
7-1 Potential Source of Contamination Inventory, Third Mesa Area
7-2 Maximum Contaminant Level Exceedance Summary, Third Mesa Area
7-3 EPA Violation Summary, Third Mesa Area
7-4 Source Water Susceptibility Analysis, Third Mesa Area
8-1 Potential Source of Contamination Inventory, Moenkopi Area
8-2 MCL Exceedance Summary, Moenkopi Area
8-3 EPA Violation Summary, Moenkopi Area
8-4 Source Water Susceptibility Analysis, Moenkopi Area
9-1 Source Water Susceptibility Summary

List of Appendices

(Provided in electronic format)

A Well Construction Details
B Well Production Data and Groundwater Modeling Results
C Supporting of Field Survey Documentation
D Water Quality Data

ED_005149_00040842-00003

List of Acronyms

AC – Asbestos concrete
ADOT – Arizona Department of Transportation
AMSL – Above mean sea level
AST – Aboveground storage tank
BIA – Bureau of Indian Affairs
BMP – Best Management Practice
CCR – Consumer Confidence Report
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
CFR – Code of Federal Regulations
CSA – Community Service Administrator
CWA – Clean Water Act
DOQQ – Digital Ortho-Quarter Quadrangles (DOQQ)
DS – Day School
EPA – United States Environmental Protection Agency
FMCV – First Mesa Consolidated Villages
GIS – Geographical Information System
GPD – Gallons per day
GPM – Gallons per minute
GPS – Global Positioning System
GWUDI – Ground Water under the Direct Influence of Surface Water
GWR – Ground Water Rule
HHS – Hopi High School
HHTA – Hopi Tribe Housing Authority
HPL – Hopi Partition Lands
HEPO – Hopi Environmental Protection Office
IHS – Indian Health Service
IOCs – Inorganic compounds
ITCA - Inter-Tribal Council of Arizona
MCL – Maximum Contaminant Level
NOI – Naturally occurring inorganic
NPDES – National Pollutant Discharge Elimination System
NPS – Non Point Source
PSOC – Potential Sources of Contamination
PVC – Polyvinyl chloride
RCRA – Resource Conservation and Recovery Act
RV – Recreational Vehicle
RO – Reverse osmosis
SDWA – Safe Drinking Water Act
SWA – Source Water Assessment
SDWIS – Safe Drinking Water Information System
SMDS - Second Mesa Day School
SOCs – Synthetic organic compounds
SWAP – Source Water Assessment and Protection
TOT – Time of travel
TMDL – Total Maximum Daily Load
USGS - United States Geological Survey
UST – Underground Storage Tank
UTM – Universal Transverse Mercator
VMC – Veterans Memorial Center
VOCs – Volatile organic compounds
VUMC – Village Utility Management Cooperative
WhAEM - Well Head Analytical Element Model
WHPA – Wellhead Protection Areas
WRP – Water Resources Program

ED_005149_00040842-00004

1.0 INTRODUCTION

In conjunction with the Hopi Tribe Water Resources Program (WRP), Tetra Tech EMI (Tetra Tech) has completed source water assessments (SWA) for all of the public water systems (PWS) that currently serve Hopi communities in northeastern Arizona. A drinking water supply is considered part of a PWS if 15 or more service connections are provided or the system serves at least 25 individuals for 60 days or more a year. The overall objective of these assessments is to improve public awareness and ultimately reduce identified threats to drinking water sources used by the Tribe. Many tribes have reported increases in contaminant threats as old infrastructure, such as septic tanks, underground storage tanks (USTs), and water/wastewater facilities deteriorate and as population centers grow. Nationwide, more than 80 percent of water systems have at least one potential source of contamination (PSOC) within two miles of the drinking water intake that threatens the supply (EPA, 2000a).

The Hopi Reservation, approximately 3,000 square miles in area, is comprised of lands surrounding the main population center (District 6), the adjoining Hopi Partition Lands (HPL), and the separate Moenkopi District. Approximately 13,000 residents live on the Hopi Reservation within 14 residential communities or villages. The majority of these residents live along the State Highway 264 corridor in villages near First, Second, and Third Mesas (Figure 1-1). However, three outlying communities exist – Spider Mound and Keams Canyon to the east, and to the west the Villages of Moenkopi located adjacent to the Navajo community of Tuba City.

The U.S. Environmental Protection Agency (EPA), under the Safe Drinking Water Act (SDWA) Public Water Supply Capacity Grant program, funded Project X-98974001-1 so that the Hopi Tribe can ultimately develop a consistently managed public water supply program on the Reservation. Past data collection efforts funded through EPA Water Pollution Control (Section 106) and Nonpoint Source Pollution Control (Section 319) Grant Programs provide much of the data basis for the SWAs. These information sources describe many of the PWS operation and management functions necessary for the Tribe to implement a source water assessment and protection (SWAP) program for the Hopi PWSs. Where appropriate, these sources of information are cited for reference within this consolidated SWA report.

This report describes completed activities and addresses the federal source water assessment requirements contained within the SDWA amendments of 1986 and 1996 for protection of public drinking water supplies. Specifically, project activities involved an inventory of all water systems, identification of PSOCs, a determination of source water susceptibility to contamination, and sharing of the SWA results with stakeholders. A brief description of Hopi regulatory programs focused on protection of natural resources is provided in Section 1.1. A detailed description of the scope of work completed for the SWAs (Section 1.2), and a discussion of the overall report organization (Section 1.3) follows.

ED_005149_00040842-00005

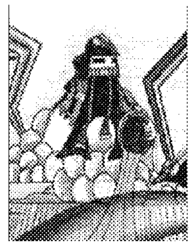
1.1 HOPI REGULATORY FRAMEWORK

The Hopi Tribe, as a sovereign nation, is responsible for protecting and managing tribal natural resources in accordance with established cultural and economic values. Accordingly, the Tribe within the framework of its Constitution and By-Laws has adopted various regulations and ordinances to protect the natural resources found on the Hopi Reservation.

Tribal programs that contribute to non point and point source pollution control include the Water Resources Program, Environmental Protection Office, Range Management Program, Sanitary Facilities Construction Program, and Solid Waste Management Program. The Hopi Tribe maintains an excellent website (http://www.hopi.nsn.us/default.asp) that describes these programs and others.

Existing implementing programs and Hopi resource protection requirements that support the Hopi SWAP objectives are described below, and summarized in Table 1-1.

1.1.1 Hopi Water Resources Program



The Hopi Tribal Council delegated authority to the Hopi Water Resources Program (WRP) to implement and enforce policies that ensure safe and dependable supply of water on the Reservation. Policies have been developed in accordance with federal SDWA and Clean Water Act (CWA) requirements. More specifically, Hopi Tribal Resolution H-107-97 enacted the Hopi Tribe Water Code, made up of three guidance documents developed in accordance with principals of sound water management and protection:

1. *Hopi Tribe Water Quality Standards (Hopi, 1997a)* – Purpose was to designate existing uses of surface and groundwater and prescribe water quality standards to sustain the use; assure that degradation of existing water quality does not occur; and to promote the social welfare and economic well being of the Hopi Tribe. Upon final EPA approval, compliance will be accomplished through permitting and management process for point-source discharges and non-point source (NPS) generators, by using the water quality standards to determine when designated use is threatened, and by using best management practices (BMPs) to control both point- and non-point sources of pollution.

2. *Hopi Tribe Wellhead Protection Manual (Hopi 1996a, and as amended in 2001)* - Purpose is to protect the water supply for residents of the Hopi Reservation and to safeguard health, resources, and property in the vicinity of existing and potential water supply wells and springs. Provides general guidance on defining areas to be protected and the PSOCs to avoid in these areas.

3. *Standard Specification for Well Construction and Pump Installation (Hopi, 1996b)* - Purpose was to require uniform standards of water supply well construction based on best available technologies and current accepted engineering practices.

ED_005149_00040842-00006

A companion document known as the Preliminary Hopi Wastewater Code is currently under review by the Tribe for adoption (Hopi, 2001a). This document outlines requirements for wastewater collection, pumping, treatment, and disposal systems with the intended purpose of:

- Protecting public health and safety by minimizing the risk of contamination of surface water, groundwater, soils, and all other natural resources by wastewater systems so that they will be available for drinking water, irrigation, recreation, and cultural uses for future generations.
- Establishing minimum criteria for the design, installation, inspection, treatment, and management of wastewater systems.

Hopi WRP plans to incorporate requirements of the programs described into SWAP program implementation. Anti-degradation provisions within the Hopi Water Code will ensure that water quality is maintained and create a process to protect against haphazard developments that can negatively impact source water quality.

1.1.2. Hopi Environmental Protection Office

In 1997, the Hopi Environmental Protection Office (HEPO) was established by the Tribe to protect Hopi lands from environmental incidents that may affect the health, safety, and well being of the Hopi people. Programs especially relevant to the SWAP include:

- *Underground Storage Tank Program* – HEPO provides compliance monitoring and technical assistance to owners/operators of local gasoline stations. The program requires that all new and existing USTs meet federal requirements to protect public health and the environment. HEPO promotes public awareness on the hazards of leaking UST's and works to protect the natural resources of the Hopi people.
- *Integrated Pest Management Program* – HEPO monitors the distribution, sale, storage, disposal and application of pesticides in accordance with federal and Tribal pesticide codes and policies. HEPO offers assistance to the public, tribal programs, and other agencies to improve understanding of pesticide hazards to human health and the environment.
- *Hopi Solid Waste Program* – Under Hopi Ordinance #44, HEPO works to ensure federal regulations are adhered to by Hopi communities. HEPO routinely receives request for assistance with identification, storage, and disposal of wastes generated on Hopi lands. The current tribal landfill and multiple closed dumpsites are monitored.

1.2 PROJECT SCOPE

Source water assessments are a process of gathering existing information and processing the data to learn more about the risks to community drinking water sources. To this end, the project necessitated a collaborative approach that included stakeholder input from multiple Hopi tribal programs (WRP, HEPO, Land Information Systems, and Facilities Management), the Bureau of Indian Affairs (BIA), Indian Health Service (IHS), village community service administrators (CSAs) and water operators, and the consultant (Tetra Tech). Five distinct geographic areas were assessed containing a total of 16 active public water systems - Spider Mound, First Mesa, Second Mesa, Third Mesa, and the Moenkopi Area (Table 1-2).

The project was completed in accordance with the general requirements of the EPA approved, Hopi WRP work plan for the source water assessments, as described below.

- *Public Water System Inventory* – Existing information was compiled on local hydrogeology, water quality, water system components, and overall PWS operation and maintenance. Topographic and aerial images were obtained to support a Geographic Information System (GIS) framework for the project.

- *Delineation of source water protection areas* – Land areas that could contribute pollutants to the drinking water supply were delineated using (1) a fixed radius of 1-mile as prescribed in the Hopi Water Code, and (2) time-of-travel groundwater modeling methods. For the second method, a 10 and 50-year time of travel (TOT) was selected due to the slow rate of groundwater movement.

- *Contaminant Source Inventory* – An inventory of all potential sources of SDWA regulated substances and other substances of concern to the community was completed. This task included integration of information from multiple Hopi programs (Section 106 Water Pollution Control, Section 319 Nonpoint Source, and HEPO programs).

- *Susceptibility Analysis* – The likelihood that inventoried PSOCs would impact the water supply was evaluated, because PSOC identification in itself does not determine which contaminants may pose the greatest threats to the drinking water source or how to prioritize their management.

- *Public Outreach* – Basic information needed to lower contamination risk is being provided through key stakeholder and public meetings and through distribution of SWA findings in the annual consumer confidence reports (CCRs) prepared for each PWS. This is an ongoing activity, and public meeting(s) to relay the results of the SWAs are planned for spring 2006.

- *Consolidated Report* – The findings presented in this report will be used to explain to local residents their source of water and what conditions and/or practices may pose threats to its quality. Moreover, it is hoped that the Tribe will use this information to develop strategies that protect community water supplies through balancing potential health risk with available financial resources.

1.3 REPORT ORGANIZATION

This introductory section is followed by three background sections that describe the technical approach used to complete the SWA (Section 2), public infrastructure (Section 3), and the hydrologic setting (Section 4). These background sections are followed by PWS specific SWA that describe source water delineation, contaminant inventory, and susceptibility analysis results. SWA are grouped by geographic area to facilitate review as follows: Section 5 – the four PWS located from near the eastern reservation boundary (Spider Mound) to the First Mesa area; Section 6 – the six PWS located in the Second Mesa Area; Section 7 – the four PWS located in the Third Mesa area; and finally Section 8 – the two PWS located in the Moenkopi District.

ED_005149_00040842-00008

Section 9 provides a project results summary and recommendations for implementation of source water protection measures. Finally, references cited throughout the report are provided as Section 10.

Referenced figures and tables are provided at the end of each report section to facilitate review. Appendix materials including well construction details, production data, and groundwater modeling results, field survey data, and water quality data are provided in electronic format to improve report distribution. A compact disk adhered to the back report cover contains most of the report files for future printing as desired.

ED_005149_00040842-00009

2.0 TECHNICAL APPROACH

The SDWA promotes a multi-barrier approach to safeguarding water supplies through delineation and prevention of contamination of drinking water sources, treatment appropriate to the quality of the source water, well-engineered distribution and storage systems, operator training and certification, and an informed public. The SWA are a key component of the multi-barrier approach.

This section describes the mechanics of completing the SWA for each Hopi PWS. The technical approach is in accordance with the EPA approved project scope outlined in Section 1.2, and technical guidance for completion of SWAs (ADEQ 1997, 1999; California, 2000; and NMED 2000).

2.1 PUBLIC WATER SYSTEM INVENTORY

Tetra Tech examined water facility documents held in the offices of the respective Village, IHS, BIA, Hopi Tribal Facilities Management Department, and EPA. The inventory also relied on the most recent PWS sanitary surveys (Cadmus, 2003 and 2004), and tribal water quality monitoring and modeling efforts to support the assessments. The information was then consolidated to form a comprehensive inventory of all Hopi water supply and delivery systems. Water supply well construction details and water production data are provided in Appendix A and B, respectively.

The inventory also includes readily available information on land use, topography, well and surface water body locations, water system construction details, and previous studies by the Tribe, federal government, and various consultants. The U.S. Geological Survey (USGS) Water Resources Division and Hopi WRP field office located in Flagstaff, Arizona provided the most complete source of reports and maintained databases. The USGS has been operating a monitoring program in the Black Mesa area since 1971 designed to determine the long-term effects of groundwater withdrawals (Truini, 2005).

A default 1-mile radius was plotted on electronic 7.5-minute topographic quadrangles coverages for each PWS supply well. Digital ortho-quarter quadrangles (DOQQs) were obtained from the Arizona Regional Image Archive and the Earth Data Analysis Center to provide aerial base coverage for the display of capture zone modeling results and identified PSOCs.

2.2 SOURCE WATER DELINEATION

Modeling of groundwater flow and chemical transport can be a detailed and complex undertaking. Often extensive data collection and complex modeling efforts are reduced by assigning larger, more protective wellhead protection areas (WHPA) such as the default 1-mile radius prescribed in the Hopi Water Code. Uncertainty is often transformed into conservative and thereby potentially overprotective assumptions (EPA, 2004).

EPA (1993a and 1993b) has proposed multiple capture zone delineation methods for determining source water areas that range from the simple (arbitrary fixed radius method) to the complex (detailed groundwater flow modeling) for source water assessments.

ED_005149_00040842-00010

As part of the source water delineation, Tetra Tech compared the default radius within the Hopi Tribe Water Code with more detailed methods including (1) calculated fixed radius, and (2) use of analytical and numerical groundwater models, since the fixed radius methods often are over protective. Subsequent to a thorough review of suggested EPA source water delineation criteria and available technical approaches, Tetra Tech selected numerical modeling for the Hopi SWAs.

An overview of the technical basis for the methods used to delineate source water areas for Hopi water supply wells is provided in the remaining subsections.

2.2.1 Delineation Criteria

EPA presents the following five criteria that can be used in combination with non-technical administrative considerations to form the basis for WHPA delineation:

1. *Distance* – Fixed radius measured from the pumping well to define the area of concern. This distance offers the first line of defense against surface contaminants that could reach the wellhead and travel down an improperly sealed borehole into the groundwater near the well intake. Distance can also be used as a setback for potential sources of microbial pathogens assuming that if they enter groundwater outside of the setback area they will become inactive before entering the well. A minimum setback distance of 50 feet for any potentially contaminating activity near Hopi supply wells is proposed for inclusion in the Hopi Water Code requirements.

2. *Drawdown* – Defines the area around the pumping well in which the water table (unconfined aquifer) or the potentiometric surface (confined aquifer) is lowered by pumping. This involves mapping the lateral extent of the cone of depression where drawdown is less than some value (e.g.1-foot). This criteria was ruled out because there is extensive regional drawdown that would result in excessively large WHPAs.

3. *Time of travel* (TOT) – Approach is based on the time required for contaminants to reach the water supply intake. The residence time criteria is based on the fact that non-conservative contaminants degrade or are retarded through sorption processes in the subsurface, and that conservative contaminant detection will give enough lead time to develop a new water supply or take immediate remedial action. TOT is calculated using representative aquifer hydraulic parameters (e.g. transmissivity, porosity, hydraulic gradient) and pump discharge.

4. *Flow boundaries* – Incorporates known locations of groundwater divides and other physical or hydrologic features that control groundwater movement, such as the lateral extent of the aquifer. For all Hopi PWS, aquifer boundaries are several miles from the pumping wells thus precluding use of this approach.

ED_005149_00040842-00011

5. *Assimilative capacity* – Based on the subsurface capacity to dilute or otherwise attenuate contaminant concentrations to acceptable levels before they reach the well. Approach requires knowledge of contaminant transport and hydrologic properties. For instance, heavy metals and viruses are not very mobile in clay-rich aquifer material, but they could migrate much farther in a fractured limestone or sandstone aquifers.

2.1.2 Selected Delineation Approaches

Several approaches were considered to delineate the WHPA for Hopi PWS. Initially, the volumetric method was used, which resulted in a 1,350-foot width WHPA for a generic 50 gallon per minute (gpm) pumping well with average aquifer characteristics. Next, potential use of the Well Head Analytical Element Model (WHAEM) was evaluated and found to be useful for simulations where recharge and discharge zones are important, such as areas where surface water and groundwater interconnection significantly affects aquifer simulation. However, for the relatively homogeneous sandstone aquifers used on the Hopi Reservation, WHAEM was considered to be of limited use and was rejected for the project.

Use of a numerical model is more precise than arbitrary distance or radius criteria (e.g., 1,350 feet or 5,000 feet). The approach is more flexible than an analytical model, allowing for variable aquifer base, confined/unconfined conditions, variable pumping conditions and flow rates, and changing boundary conditions over time (for example, future drawdown from coal mining scenarios). Output can also be compared with the existing USGS Black Mesa model, and with previous numerical modeling studies (DBS&A, 2000a and 2003).

The primary groundwater sources, the D- and N-aquifers, on the Hopi Reservation have been the subject of much study over the last two decades, so aquifer characteristics are available (Section 4). The USGS Black Mesa groundwater flow model (Eychaner, 1983; Brown and Eychaner, 1988) provided a benchmark for use of a numerical groundwater flow model. The MODFLOW modeling package (McDonald and Harbaugh, 1988) coupled with MODPATH particle tracking code (Pollack, 1989) was used to delineate the capture zones.

The numerical models developed for this study also allow well interference effects, and future well locations to be evaluated. Finally, MODFLOW is fully integrated with the contaminant transport model MT3D, so the models can be adapted to define wellhead protection areas based on assimilative capacity, the most precise WHPA delineation criteria, in specialized areas (for example, where underground storage tanks or other contaminant sources have been found to contaminate groundwater).

2.2.3 Construction of Numerical Groundwater Models for Source Water Delineation

Separate numerical model domains were constructed for First Mesa, Second Mesa, Third Mesa, Moenkopi Wash, and Spider Mound areas (Appendix B). Most model domains are oriented northeast-to-southwest which parallels the USGS Black Mesa model. Trial runs showed the optimum model domain size is about 10 miles wide and 25 miles long. The selected model domain size allows pumping wells in each wellfield to be simulated without creating artificial boundary effects.

The Moenkopi Wash model was oriented north-south, parallel with the ambient groundwater flow direction. The modeling exercise was simplified to simulate conditions with a single homogenous aquifer layer.

In order to allow for importing/exporting of model results to GIS, the data were linked with real-world coordinate system universal transverse Mercator (UTM) projections. This allowed field coordinates from GPS readings to be directly used to ensure proper location of the wells, which was important in areas with closely-spaced wells to account for interference effects. The cell sizes in each model vary from as small as 10 meters square to as large as 1,000 meters square.

For the First Mesa, Second Mesa, and Third Mesa models, data from the USGS model were adapted for input. The elevations of the top and bottom of the N-aquifer were input separately by interpolating the data from the USGS Black Mesa model. Saturated thickness was also taken from the USGS model, and varied from 100 to 500 feet. The N-aquifer in these three model areas were simulated as under completely confined conditions, with water level elevations above the top of the layer. Initial heads were also taken from predevelopment conditions of the USGS model, with constant-head conditions set at the upgradient (northeast) and downgradient (southwest) boundary cells.

The Moenkopi model relies on data obtained from previous studies in the area related to a source water assessment (DBS&A 2000a) and well field development (Tetra Tech, 2004). The top of the N-aquifer was input as rising several hundreds of feet to the northeast, allowing for unconfined conditions in this model domain. To avoid boundary condition effects, the model domain width was set at about five miles from the pumping wells. Regional aquifer discharge to Moenkopi Wash was input as constant-head cells, with other constant-head cells at distant locations about five miles to the northeast based on the regional water table gradient. Aquifer permeability was assumed to be similar to values used in the USGS Black Mesa model.

The Spider Mound model was created using local well data, and the aquifer was simulated as confined. With no definitive data on subsurface geometries, the strata were input as flat lying. The hydraulic gradient was input at 0.0042 based on a water table drop from 6,200 ft above mean seal level (amsl) in the northeast to 5,650 ft amsl in the southeast over a distance of 25 miles.

Well pumping schedules were developed assuming that the wellfields were all at predevelopment conditions in 1955. Starting with steady-state initial heads, pumping was then graduated in ten-year increments in a transient simulation to reach metered data from 2005. Future pumping estimates were made by extrapolating a growth rate of two-percent (2%), with a maximum capacity limits placed on each well. A pumping schedule summary for each model is provided in Appendix B.

A limited sensitivity analyses was conducted using the First Mesa model to explore possible variation in capture zone geometry. In the first set of sensitivity analyses, the effective porosity was reduced to a value of 5-percent. The resulting capture zone geometries were slightly wider and much longer then the base case. In the second set of sensitivity analyses, the upgradient head was reduced by 55 meters (almost

200 feet) to account for the possible regional water level decline projected from groundwater withdrawals at the coal lease. The amount of water level decline was based on results of the USGS model at the upgradient boundary of the First Mesa model. The analysis showed that capture zone geometry is not sensitive to the change in gradients.

Protection zone boundaries must be established far enough from the well head that any contaminant releases occurring upgradient of the well can be mitigated within a reasonable time frame before posing a threat to the well. This time frame is defined by the time-of-travel (TOT) specified for the capture zone models. MODPATH reverse path tracking was used to define capture zones because it outlines the well recharge area and TOT for a conservative, non-retarded contaminant. Particles were backward-tracked from 2055 to 2005 to delineate 50-year capture zones given the unique pumping schedules, locations, and aquifer parameters at each well location. The same technique was applied with ten-year backward-tracking from 2015 to 2005 to delineate 10-year capture zones.

2.3 CONTAMINATION SOURCE INVENTORY

All chemical and microbial contaminants were inventoried based on field surveys completed with the assistance of Tribal personnel familiar with each community/village, the review of water quality data, database searches, and the compilation of relevant information from scattered sources. The field surveys were conducted over the period of May through August 2005. Appendix C contains example field forms, summary of well integrity evaluation, PSOC codes related to various land use activities and specific contaminants, and representative photographic documentation to support the SWA described in Sections 5 through 8.

Potential microbial, chemical, and radiological contaminants were inventoried through review of water quality data, database searches, field surveys and other sources as described below.

- Pertinent PWS information from existing water operator files (i.e., number of wells in system, well construction, and sanitary survey data)
- HEPO and Hopi WRP regarding applicable environmental reports
- BIA Area Office in Keams Canyon
- IHS and Hopi WRP for well data; water system layout
- EPA Region 9 databases (e.g. CERCLIS, RCRIS, SDWIS)

2.3.1 Field Surveys

During the field survey two forms were completed; *Form 1 - Well Data Sheet* and *Form 2 - PSOC Checklist*. Form 1 contained the bulk of the information on the well site and was used to determine the sensitivity of the water source to contamination. Information such as depth of well, depth of screened interval, well construction and integrity, physical integrity of supply well (e.g., is well prone to flooding, is well properly sealed, etc.) were developed using this form. *Form 2 - PSOC Checklist* provided codes for various PSOC associated with agricultural, commercial, industrial, and municipal/residential land uses. For example, if a commercial gasoline service station was found in the area of delineation, the field

ED_005149_00040842-00014

team would check the appropriate PSOC code for commercial gasoline service station on Form 2 and provide and assign a potential risk factor (high, medium and low risks).

Field surveys consisted of a walking and/or driving survey within the boundaries of the administrative protection area defined by the 1-mile radius for each well, and documenting well site conditions. PSOC s, and key water system features were documented on field forms and geo-referenced using a hand-held global positioning system (GPS) unit (Garmin-76 Marine Navigator, UTM Location Format, NAD83, Map Datum). PSOC codes were labeled on field copies of the topographic and aerial base maps.

Photographs were taken of each wellhead, the exterior and interior of the control building, and significant PSOC. Location data was exported into a GIS for data presentation. Hopi Land Information Systems (LIS) personnel will hopefully be able to periodically update the contaminant inventory location database.

2.3.2 Water Quality Data

The SDWA authorized EPA to identify contaminants and to establish drinking water standards for public water supplies. All owners or public water systems are required to comply with primary (health-related) standards and are encouraged to attain secondary, or aesthetic standards (nuisance-related standards, e.g. taste and odor). Water quality standards are enforced through testing water supplied to customers and measuring samples against maximum contaminant levels (MCLs). Contaminants regulated under the SDWA and their respective maximum contaminant levels (MCLs) are provided in Appendix C or can be obtained directly from EPA's website (www.epa.gov/safewater/mcl.html).

Tetra Tech obtained sample results from the Safe Drinking Water Information System/Federal Version (SDWIS/FED), EPA's national database of water quality, monitoring and reporting, significant consumer notification and variance or exemption violations of States and Tribes. Public water systems in Indian country are required to report laboratory data to EPA. EPA uses the information to determine compliance with the national primary drinking water regulations of SDWA. If a system does not monitor the quality of its water, it is impossible to know if it complies with health-based requirements. For this reason, EPA considers the failure of a water system to monitor and report as required a major violation that must be addressed and corrected.

Appendix D provides monitoring and regulatory compliance information, including an EPA compliance summary of monitoring requirements tables that show the monitoring frequency required for chemical constituents. The EPA compliance summary data is for the period of 1993 through August 2005. USGS water quality sampling results from the Black Mesa monitoring program are also provided as appropriate.

The present and future requirements of the SDWA, including analytical monitoring and groundwater treatment, are likely to place substantial financial demands on the PWSs. The information base and analysis from the source water assessments is vital to monitoring flexibility of variances and exemptions to small water systems.

ED_005149_00040842-00015

2.4 SUSCEPTIBILITY ANALYSIS

Susceptibility can be defined as a combination of sensitivity of the water source to contamination due to characteristics of the source area, and the vulnerability of the water source to contamination due to characteristics of the contaminant. Vulnerability is determined by the characteristics of the contaminant, the likelihood of contaminant discharge, spill or accidental release, and the number of PSOCs and their proximity to the groundwater supply

Tetra Tech ranked PSOCs to identify activities that should be targeted for immediate corrective action. Such potentially high-risk contaminant sources include underground storage tanks and waste disposal sites, which are often already under some type of monitoring program. As defined by EPA (1993b), protection areas are established to guard against three main types of threats.

1. Direct introduction of contaminant contiguous to the well through improper casing, road runoff, spills, and accidents.
2. Microbial contaminants such as bacteria and virus pathogens.
3. A broad range of chemical contaminants, including inorganic and naturally occurring or synthetically derived organic chemicals.

The susceptibility determinations are provided in Sections 5 though 8 for each PWS using the risk ranking process outlined in *Protecting Drinking Water: A Workbook for Tribes (Totten, 2000).* The purpose of the risk ranking is to identify drinking water sources that are most vulnerable to contamination. The factors used in the susceptibility determination for groundwater systems include:

- *Contaminants* - Numerical score based on contaminant type and concentration. Each PSOC was ranked as having a high concern (3), moderate concern (2), or low concern (1). High-ranked contaminants are chemicals such as carcinogens, and chemicals or biological contaminants for which maximum contaminant levels (MCLs) have been established. Rankings considered both the toxicity of the contaminant and the potential quantity present at the source site. Thus, even a small amount of a highly toxic contaminant such as arsenic may warrant a high ranking.

- *Location* - Numerical score based on distance of the PSOC from the drinking water source. Contaminant sources located inside the 50 year TOT delineated area are given a higher weight (1) because distance from the wellhead or intake structure tends to reduce the concentration of contaminants

- *Natural Barriers* - Numerical score based on naturally occurring surface or subsurface conditions that inhibit the contaminant from reaching the drinking water source or reduce their toxicity. Naturally occurring surface or subsurface conditions that inhibit the contaminant from reaching the drinking water source or reduce their toxicity were rank as high (0), moderate (1), or low (2) for each PSOC.

  Natural barriers are features such as subsurface fine-grained layers (clays, mudstone, and shale) that tend to block or slow down the movement of contaminants toward a drinking water source. The presence of these barriers can reduce the potential for contamination by reducing the concentration of a contaminant or neutralizing it through natural processes. Aquifers overlain with fine-grained layers tend to have higher natural barrier effectiveness.

ED_005149_00040842-00016

- *Intake or Well Integrity* - Numerical score based on the condition of the well. Physical integrity of water intake or well site in regard to conveyances, intake pumps, wellhead apparatus, sanitary seals and distribution system integrity were ranked as good (0) or poor (1).

- *History* - Numerical score based on historical water quality data and maximum contaminant level (MCL) exceedances. Historical water quality data and MCL exceedances provide an indication of the source water susceptibility. A history of contaminant detection for a particular contaminant related to an identified PSOC is scored as a yes (1) or no (2) depending on whether there was a historical MCL violation for the water system.

With the exception of the Moenkopi area, all wells are completed within confined aquifer areas meaning they occur beneath less permeable materials and are under pressure conditions greater than atmospheric. Despite this generally less vulnerable condition, confined aquifers are susceptible to contamination from a variety of factors - the relative differences in head between the aquifer and other aquifers, natural or human-induced breaks in confinements such as fault zones or abandoned and corroded well casing, and the physical condition of the confining unit itself. Unconfined aquifers are generally more vulnerable to contaminants originating at or near the surface than confined aquifers.

The numerical scoring system provides a "relativity rank" for the vulnerability of the drinking water source to each PSOC; the higher the score, the higher the potential for contamination from any particular source. The numerical score serve as a basis for comparison among contaminant sources and drinking water sources. Totaling all the numbers across the matrix yields an approximation of how serious a risk each potential contaminant source poses to a particular drinking water supply. Deciding which potential contaminant sources to address in the protection phase of the SWAP program will depend on Tribal priorities, resources, and input from the local community.

Systems with a "High" susceptibility rating are strongly encouraged to implement management controls within the source water assessment area to minimize the threat of these potential sources of contamination. Source water areas with a "Medium" susceptibility rating should consider implementing source measures that reduce the risk of potential contamination from sources closest to the well/intake. Systems with a "Low" susceptibility determination should initiate a public education and outreach program that focuses on protecting the drinking water resource and informing the public about activities that threaten the quality of the drinking water supply.

ED_005149_00040842-00017

3.0 PUBLIC INFRASTRUCTURE

This section provides an overview of Hopi land use patterns (Section 3.1), public water systems (Section 3.2), and associated infrastructure supported by current water service areas (Section 3.3).

3.1 LAND USE PATTERNS

Populated areas consist of 14 residential areas scattered across the central part of the Hopi Reservation (Figure 1-1). Land surrounding the villages and residential areas is typically used for farming, grazing, subsistence gathering, and religious purposes. Traditional village, clan, and religious authorities regulate use of these lands, and they are often subject to conflicting jurisdictional claims by the villages, clans, or families holding customary-use rights to them. Lands farther from the villages are used primarily for grazing, but also support uses such as secondary homes, farming, gathering, and recreation.

Approximately 8,000 acres of the Reservation are cultivated using dryland farming techniques. Farmland is typically restricted to small, 1- to 5-acre plots on the broad alluvial valleys located below the mesa tops. For the most part, Hopi farmers do not apply fertilizers or pesticides to their farmland. Crop production was the traditional mainstay of the Hopi people and remains an important cultural activity. However, over the past century livestock grazing has surpassed crop production in economic importance. The scarcely populated lands away from the main population centers are divided into a number of range units to manage the distribution of livestock and grazing.

Tribal members often use a variety of economic strategies to survive. Many combine full-time or part-time work with livestock grazing, making and selling of handcrafts, selling surplus crops, and gathering various materials for their own use or for sale. Much of this mixed cash/subsistence/traditional economy is based on land and resource use.

The Tribe has mapped the location of various pollution sources so that watershed restoration priorities could be established. NPS from failing wastewater systems, livestock impacts to riparian ecosystems, and severe soil erosion were identified as the greatest surface water quality concerns. Point source pollution is limited primarily to underground storage tanks and solid waste disposal areas. A more detailed discussion of NPS pollution sources can be found in the Hopi Nonpoint Source Assessment (DBS&A, 1997) and Hopi Watershed Protection and Restoration Guidelines (DBS&A, 1999a).

3.2 PUBIC WATER SYSTEMS

Drinking water is provided to most residents by 16 active PWS systems operated and maintained by multiple organizations including ten independent village water committees, a non-profit village cooperative, the U.S Bureau of Indian Affairs (BIA), and the Hopi Tribe Department of Facilities Management as summarized in Table 3-1. PWS operators provided by the Tribe received Level 1 certification through the Inter-Tribal Council of Arizona (ITCA), and most water operators employed by independent communities have also obtained the ITCA Level 1 certification.

ED_005149_00040842-00018

Approximately 13,000 residents are served by 1,900 service connections. Figure 3-1 shows the location and extent of the water service areas provided by each PWS.

Most of the PWSs were constructed with federal funds over a 30 year period spanning the late 1950s through late 1980s. IHS typically provided assistance with infrastructure design, construction, and initial operation. Existing water wastewater service is not comprehensive, and most village systems are in need of upgrading to keep up with existing sanitation needs. PWS components such as water sources, storage tanks, distribution, and system deficiencies are summarized in Table 3-2 for each system.

In 1993, the Tribe completed a comprehensive evaluation of existing PWSs operation and maintenance (DBS&A, 1993a). The study noted the advancing age of many of the system components including water storage tanks, control systems, and submersible pumps. Common system deficiencies from the study and current conditions as determined from most recent sanitary surveys (Cadmus, 2003 and 2040) and Tetra Tech field surveys are described below.

- *Chlorination systems absent or inoperable* - All PWSs now have chemical metering systems at the pump house or chlorine is added manually at the water storage tank site to maintain residual chlorine disinfectant in the distribution systems.

- *Record keeping incomplete or unavailable* - All PWSs record flow meter readings; however, frequency, completeness, and availability still varies significantly between systems. Incomplete flow meter records, water quality data, and maintenance records remain an issue for many villages due to the frequent changes in administration and operator staff.

- *Spare parts unavailable* - Many PWS now maintain a limited parts inventory. Although, major repairs still require significant down time and are problematic for single water source systems.

Many village water associations continue to experience difficulties with high operator turnover, poor user fee collection, lack of finances, and meeting SDWA requirements overall. Throughout the 1990s, there were significant attempts to create a central utility organization. In 1997, the Hopi Tribal Council approved a charter and incorporation of a non-profit cooperative business known as the Village Utility Management Cooperative (VUMC) owned by the self-governing villages. The stated goal was to assist villages in management, operation, and maintenance of their water systems. Any community water and sewer service provider was eligible to become a member of and receive water and sewer management, and maintenance services from the VUMC. However, low membership and general distrust prevented the VUMC from growing to serve more than a couple of villages. Most water and wastewater systems continue to be operated and maintained by independent village water associations.

The IHS (1991) justification for proposing a tribal utility authority remains true almost 15 years later: many water associations continue to incur operating expenses that exceed revenues. Although significant improvements have been made in overall PWS operation, water quality testing, water/wastewater operator certifications, and significant financial constraints still limit effective PWS operation.

ED_005149_00040842-00019

Because Hopi PWSs are managed and operated by a multitude of entities there are no central repositories for construction, operation, and compliance records for the water systems. The Hopi WRP continues to working closely with village water operators to ensure that pertinent information is collected and stored for future reference. As part of the SWA, Tetra Tech has compiled readily available information on well construction, aquifer use, static water levels, pumping rates, and current usage status for this report. Table 3-3 provides an inventory of the 27 PWS supply wells currently supporting drinking water needs across the Reservation, the geographic alignment of these PWS is provided in Table 1-2.

3.3 SUPPORT INFRASTRUCTURE

Support infrastructure has developed in a rather piecemeal fashion. Limited infrastructure, in particular a lack of reliable electrical supply, is perceived as severely constraining economic development and new housing on the Reservation. The *Hopit Tunatya'at 2000: The Hopi Strategic Land Use and Development Plan* (Hopi, 2001b) provides a comprehensive review of private, federal, tribal, and village activities that are supported by the PWSs. Existing infrastructure and development plans are summarized in the following subsections.

3.3.1 Tribal and Federal Facilities

Hopi Tribal government is housed in several buildings located in Kykotsmovi. The Tribe owns and operates the Hopi Veterans Memorial Center (VMC) as a multipurpose recreational facility located on the western slope of Second Mesa. Other recreational facilities include an overnight camping area at the Hopi Cultural Center, several rest stops along State Highway 264, and picnic areas along reservoirs located in Keams and Pasture Canyons. The tribal government also owns and operates the only motel/restaurant complex on the reservation known as the Hopi Cultural Center located on Second Mesa.

Police services are provided by BIA and Hopi Tribe Rangers that are located in Polacca and Kykotsmovi, respectively. The county sheriff and Arizona Department of Public Services patrol the state highways that traverse the reservation (Hwy 77, 87, and 264). The Hopi Health Care Center, located immediately west of Polacca, provides emergency and routine medical services. In 2001, a second EMS and fire response facility was constructed in Kykotsmovi. Fire response services remain extremely limited with only BIA maintaining structural fire fighting equipment to protect federal government facilities located primarily in Keams Canyon (Hopi, 2001b).

Six primary grade schools (Polacca Day School, First Mesa Elementary, Second Mesa Day School [under construction], Kykotsmovi Day School, Hotevilla Day School, and Moenkopi Day School) are either operated by BIA or under contract with the Hopi Tribe. A private Christian mission school is located in Kykotsmovi. Under a BIA contract, the Hopi Tribe operates the Hopi High School that serves the main reservation secondary-school population. Northland Pioneer College and Northern Arizona University (NAU) offer community college level courses in the Polacca area.

ED_005149_00040842-00020

3.1.2 Village/Community Development

A reservation paradox exists in that, in the Hopi Partition Lands (HPL) and peripheral areas of District Six, development is precluded by the lack of infrastructure; while constraints imposed by complex land tenure and assignment processes impede new houses or businesses in areas where infrastructure does exist – namely the villages and community mixed use areas (Hopi, 2001b). The Hopi constitution specifically provides the villages and clans with jurisdiction and control over land within their traditional boundaries at the time the constitution came into effect. In general, land outside of District Six falls under the administrative jurisdiction of the Tribal Council. The tribal government also maintains considerable management responsibilities for land development and oversees all environmental and cultural protection measures.

Specific village land use and area structure plans need to be advanced to reduce sprawl development along the State Highway 264 corridor. Village and clan leader participation must continue to be engaged in plan-making processes. It will be only through such a process that a balance in the allocation of development between and among the villages and the HPL will be achieved (Hopi, 2001b).

The Hopi website lists the following projects that are in the planning or construction phases:

- *First Mesa* - Tewa Village Administrative Building, Polacca Headstart, State Highway 264 expansion near First Mesa Elementary School, Hopi Judicial Complex Expansion, Hopi Tribe Housing Authority (HTHA) scattered sites access roads and utilities, First Mesa Youth Center, and Polacca airport development.

- *Second Mesa* - Shungopavi EPA/IHS water and wastewater projects, Hopi Cultural Center expansion, new library, Headstart, Second Mesa Day School, HTHA scattered site access with roads and utilities, Second Mesa Clinic, Second Mesa Guild.

- *Third Mesa* – Kykotsmovi store, HTHA subdivision, Conference/Wellness Center Expansion at HVMC, new site for Amerigas, HTHA scattered sites access roads and utilities; Oraibi Community Building; Hotevilla Youth/Elderly Center, and Bacavi HTHA scattered sites access roads and utilities.

- *Moenkopi* - EPA Water Project, Bath House Project [Lower Village], U.S. Highway 160/State Highway 264 widening and drainage, Moenkopi Motel, Moenkopi Trailer Park, Waste Water Treatment Facility, Moenkopi Elderly Center.

The Hopit Tunatya'at 2000 calls for development of six new locations, five of these are located on main reservation and Moenkopi District land and the sixth on trust property near Winslow, south of the reservation. Two projects are tribal government initiatives (Tawaovi and Winslow), two are village government initiatives (Howell Mesa East and Moenkopi) and two are new community "organic growth" developments (Yu Weh Loo Pahki commonly known as Spider Mound and Side Rock Well). Public drinking water supplies will be key to growth of these new developments and the existing Hopi villages and communities.

4.0 HYDROLOGIC SETTING

This section provides an overview of factors that control the distribution of groundwater resources across the reservation.

4.1 CLIMATE AND SURFACE WATER DRAINAGE

The climate is semiarid with precipitation ranging from 7- to 18-inches per year. The amount of precipitation strongly correlates with elevation, as the maximum occurs in the high northern areas of Black Mesa. The majority of precipitation occurs as thunderstorms during the period of July through October. This period accounts for more than 80 percent of the annual stream flows. Winter storms are attributed to be the source of most aquifer recharge.

The reservation is drained by five major washes: Moenkopi, Dinnebito, Oraibi, Polacca, and Jeddito (Figure 1-1). The washes originate on Black Mesa and flow southwest toward the Little Colorado River. The washes are generally ephemeral; however, intermittent and perennial reaches exist as a result of groundwater discharge.

4.2 GEOLOGY

The area is located within the south-central part of the Colorado Plateau physiographic province and falls within the Black Mesa hydrogeologic subdivision, which is a large moderately dissected highland that occupies the structural center of Black Mesa Basin (Cooley, 1969). Black Mesa rises approximately 3,000 feet above the surrounding lowlands on its northeast edge and then slopes gently to the southwest, where it eventually becomes indistinguishable from the surrounding lowlands. The relatively tectonically stable region was moderately affected by Late Cretaceous through Early Tertiary folding pressures that formed several broad, generally northwest trending, anticlines and synclines.

The surficial geology of the Black Mesa area is shown on Figure 4-1. A thin mantle of unconsolidated deposits is underlain by thick sequences of relatively flat lying Permian to Late Tertiary age sedimentary rocks. The sequence consists of up to 10,000 feet of interbedded sandstone, mudstone, siltstone, limestone, coal, and gypsum deposits (Lopes and Hoffman 1997). Surface rock formations become progressively younger heading from outlying areas such as the Little Colorado River were the Triassic age Chinle Formation is present toward the center of the Hopi Reservation where Cretaceous age Mesa Verde Group sediments are present.

Figure 4-2 illustrates the regional stratigraphy and indicates water-bearing formations of importance for the SWA. Currently, water bearing rocks of Jurassic and Cretaceous age provide all drinking water sources for the Hopi PWSs. In the Moenkopi area, the uppermost rocks present at ground surface are Navajo Sandstone.

ED_005149_00040842-00022

Extensive reviews of the regional geology can be found in documents prepared by other investigators (Cooley, 1969; Lopes, 1997; Truini, 2003, Tetra Tech, 2004). A description of the rock formations that are of primary importance for the SWA presented in descending order follow.

4.2.1 Mesa Verde Group

The Cretaceous age Mesa Verde Group consists of the Yale Point Sandstone, and the Wepo and Toreva Formations. The Yale Point Formation consists of yellowish-gray medium-grained sandstone. The Wepo Formation consists of alternating beds of olive-gray to yellowish-brown siltstone, mudstone, coal, and sandstone. Finally, the Toreva Formation consists of yellowish-gray sandstone interbedded with carbonaceous mudstones of varied colors.

On the Hopi Village mesa tops served by PWSs, the Toreva Formation is present from ground surface to a depth of approximately 280 feet below ground surface (bgs). The sandstone members of the Toreva Formation form the vertical cliffs of the Hopi mesas. The contact with the underlying Mancos Shale is a depositional gradation.

Mesa Verde Group sediments are absent south of the Hopi mesas due to erosion.

4.2.2 Mancos Shale and Dakota Sandstone

The Mancos Shale consists of alternating thick zones of light gray to dark gray shale, with sandier yellow-gray sections. The shale was deposited in the Cretaceous Interior Seaway, which stretched north-south from Canada to the Gulf of Mexico during the time of deposition. The gray color likely results from high organic content and reducing conditions during deposition. The Mancos Shale is approximately 450 feet thick where protected from erosion by the overlying Mesa Verde Group sediments. Below the Hopi mesas, the Mancos Shale ranges in thickness from approximately 150 to 300 feet. The Mancos Shale is the primary aquiclude, or hydraulic barrier, separating the sandstone aquifers of the Mesa Verde Group from the underlying D-aquifer described in Section 4.3.

The Dakota Sandstone has been interpreted as a shoreline facies of the Cretaceous Interior Seaway. It generally consists of a lower pale orange sandstone with a dark grayish brown middle carbonaceous coal unit, and an upper layer of marine shale and sandstone. The Dakota Sandstone is the primary water-bearing unit in the D-aquifer system, and is approximately 100 feet thick across the reservation.

4.2.3 Morrison Formation/Cow Springs Sandstone

The Morrison Formation consists of fine-grained continental, lake and stream deposits. The unit intertongues with the wind-deposited Cow Springs Sandstone, and grades into the upper units of the San Rafael Group. Rocks are greenish gray to yellowish gray fine-grained sandstone and siltstone. The unit is approximately 200 feet thick across the reservation.

ED_005149_00040842-00023

4.2.4 San Rafael Group

The San Rafael Group is comprised of the Entrada Sandstone and Carmel Formation. The Entrada Sandstone consists of a reddish brown silty upper member and a reddish orange to grayish orange sandy lower member. The Entrada Sandstone is the oldest member of the Dakota multiple aquifer system (D-aquifer) and is approximately 150 feet thick. The Carmel Formation consists of grayish red to pale red siltstone and mudstone beds in series with greenish gray to white strongly cemented sandstone, and thin sandy limestone beds (Harshbarger, 1957). The Carmel Formation ranges from 45 to 130 feet thick across the reservation and forms the upper confining bed of the N-aquifer system (DBS&A, 1998).

Because the Navajo Sandstone wedges out to the southeast, the San Rafael Group directly overlies the Kayenta Formation in the southeastern part of the reservation.

4.2.5 Glen Canyon Group

The Glen Canyon Group, a sequence of orange-red and grayish sandstone and siltstone beds, includes in descending order the Navajo Sandstone, Kayenta Formation, and Wingate Sandstone. The Navajo Sandstone and upper Wingate Sandstone are medium-to very fine-grained, weakly cemented sandstone, that in outcrop, contain readily observable large-scale cross beds typical of wind deposited sediments. In contrast, the Kayenta Formation is composed of fine-grained siltstone and silty sandstone with interbedded mudstone and thin limestone beds deposited primarily by streams.

The Navajo Sandstone is the main unit of the N-aquifer, and ranges in thickness from approximately 400 feet at Hotevilla to less than 150 feet at the Hopi High School. Near Moenkopi, the silty facies of the Kayenta Formation is approximately 500 feet thick (Harshbarger, 1957 and Tetra Tech 2004). The thickness of the Wingate Sandstone is unknown as Hopi supply wells have not penetrated this unit. Regionally, the Wingate Sandstone is known to wedge out to the northwest, and the other two formations wedge out to the southeast.

The rock units are exposed at the surface around the perimeter of Black Mesa, but dip into the structural basin to more than 1,500 feet bgs. The group is underlain by more than 1,100 feet of low-permeability rocks of the Chinle and Moenkopi Formations of Triassic age (Eychaner, 1983 and Tetra Tech, 2004).

4.3 GROUNDWATER OCCURRENCE

As defined by Cooley (1969), groundwater on the Hopi Reservation occurs entirely within the Black Mesa groundwater basin. In descending order exploitable groundwater occurs in the following aquifers: Measaverde Group (T-aquifer), the D-aquifer, and N-aquifer.

Other potential water supplies include the alluvial fill along the main washes and the Coconino Sandstone (C-aquifer), which will likely be developed to support population growth along the western and southern

ED_005149_00040842-00024

boundary of the reservation at locations such as Moenkopi (Section 8). These aquifers are composed of sandstone beds between nearly impermeable layers of siltstone and mudstone.

4.3.1 T-Aquifer

The Mesaverde Group (T-aquifer) has been divided into three formations as described in Section 4.2.1. Sandstone units within the Toreva and Wepo Formation are the primary water-bearing units of the Mesaverde Group and are unconfined in most locations where groundwater resources have been developed. Although these units typically yield only relatively small amounts of water to wells and springs (less than 5 gpm), they are still considered important water supplies for ceremonial and livestock purposes in the vicinity of the Hopi mesas. Recharge to the Mesaverde Group occurs along outcrop areas around Black Mesa. Discharge from the T-aquifer occurs as spring flow and from limited pumping of domestic and stock wells.

4.3.2 D-Aquifer

The D-aquifer consists primarily of the Dakota Sandstone and Cow Springs Sandstone separated by thick sequences of low permeability mudstone and siltstone. However, the Entrada Sandstone and Carmel Formation are also hydraulically connected to the D-aquifer and are commonly considered to be part of the system. Groundwater in the D-aquifer occurs under confined conditions throughout most of the reservation, although unconfined conditions occur toward the south, where the overlying and confining Mancos Shale is not present. The D-aquifer is moderately permeable, and typical well yields are on the order of 5 to 20 gpm. D-aquifer withdrawals are typically by windmills for livestock watering and by a few municipal wells.

Water quality is highly variable and considered to be poor in many locations with total dissolved solids (TDS) concentrations ranging from 1,000 to 3,000 mg/L. The D-aquifer is recharged primarily in the eastern part of Black Mesa where D-aquifer rocks crop out. Discharge from the D-aquifer occurs as spring flow and seepage along the perimeter of Black Mesa. Discharge also occurs into alluvium-filled stream valleys and as interformational downward leakage.

4.3.3 N-Aquifer

The N-aquifer system consists of (in descending order) the Navajo Sandstone, the sandy facies of the Kayenta Formation, and the Wingate Sandstone. The Navajo Sandstone is the primary water-bearing unit in the N-aquifer system and is the most important aquifer in the Black Mesa basin. Groundwater in the N-aquifer is confined underneath Black Mesa and the Hopi villages, but becomes unconfined along the margins of the basin where it crops out. The N-aquifer is used by the Navajo Nation and the Hopi Tribe for household, agricultural, municipal, and industrial purposes, and by Peabody Western Coal Company (PWCC) for its coal slurry line.

Groundwater in the N-aquifer system is recharged primarily along the Navajo Sandstone outcrop north and northwest of Black Mesa near Shonto.

ED_005149_00040842-00025

Some recharge may also occur as leakage from overlying formations within the confined portion or as localized recharge within the unconfined southwestern outcrop areas. Groundwater flows south and southwest and discharges to springs as seepage along the southern and western margins of the N-aquifer, south and west of the Hopi villages. N-aquifer water also discharges to Moenkopi and other washes (as baseflow) and to numerous water supply wells that tap the aquifer. Groundwater ages increase gradually from a few thousand years near Shonto to about 35,000 years in the central confined part of the aquifer, and modern recharge rates have been estimated at roughly 3,000 acre-feet per year (Lopes, 1997).

The D- and N-aquifers are separated by a low permeability confining unit, or aquitard, consisting of the lower Entrada Sandstone and the Carmel Formation. This confining unit restricts the downward flow of poor quality water from the overlying D-aquifer into the underlying N-aquifer; however, chemical similarities along the southern margins indicate potential leakage of groundwater from the D-aquifer to the N-aquifer (Lopes, 1997 and Truini, 2003). A study of the Carmel Formation as a confining unit has been proposed by the USGS to better understand whether leakage is occurring naturally and/or if pumping from the N aquifer is inducing leakage from the overlying D-aquifer.

In most areas, the water quality of the N-aquifer system is excellent, with total dissolved solids (TDS) generally ranging from 100 to 400 mg/L. However, isolated N-aquifer wells located around the perimeter of the confined areas can yield poor quality groundwater.

4.3.4 C-Aquifer

Groundwater in the C-aquifer occurs in the Coconino Sandstone, in the upper part of the Supai Formation, and in the Kaibab Limestone. Groundwater in the C-aquifer flows to the west and northwest from the principal recharge area along outcrops located east of Black Mesa. The transmissivity and water quality of the C-aquifer is highly variable, requiring treatment in most cases. The great depth to the C-aquifer (e.g. 2,000 feet or greater) precludes it from being an economically viable resource were alternate water sources are available on the reservation.

The Hopi Tribe has recently completed an exploratory well in the Moenkopi area to evaluate potential use of the C-aquifer to supplement water needs for the Villages of Moenkopi near Tuba City (Tetra Tech, 2004).

ED_005149_00040842-00026

5.0 SPIDER MOUND AND FIRST MESA SOURCE WATER ASSESSMENTS

This section describes the source water assessments completed for PWSs that serve the Spider Mound Area and First Mesa Area. For each PWS, the discussion includes information on (1) general system operation, (2) source water delineation, (3) contamination source inventory, and (4) susceptibility analysis. The PWS descriptions draw from the most recent sanitary surveys completed by Cadmus (2003 and 2004).

Summary information on PWS administration, system components, well construction, and aquifer characteristics can be found in Tables 3.1 through 3.3. Specific information is repeated in this section as necessary for SWA completeness.

5.1 SPIDER MOUND (Yu Weh Loo Pahki)

Spider Mound (PWSID #090400688) PWS serves a rural residential area located in the extreme southeast corner of the Hopi Reservation near the intersection of State Highways 77 and 264 (Figures 1-1 and 3-1). The community is based on a scattered home site development created under the HPL land assignment guidelines in four range units. The scattered home sites are assigned to families who relocated to the HPL from the Jeddito area of the Navajo Reservation (Hopi, 2001b).

The PWS is comprised of a single D-aquifer well source located adjacent to a two-room well house containing pump controls and chlorination equipment. The water is pumped from the well house to a 100,000-gallon steel standpipe where it gravity flows through approximately 22 miles of 4-inch schedule 40 PVC distribution system piping. The distribution system is approximately 10 years old and reported to be free of leakage problems.

A second supply well was constructed in 2003, but the infrastructure required to connect the well to the distribution system has not been built because the water source exceeds the maximum contaminant level (MCL) for fluoride. Although a common water additive to promote strong teeth, excessive amounts of fluoride can result in mottled teeth for children and bone disease in adults over prolonged periods of use.

The system actively serves 13 residences, while another five residences are connected to the system but are not in use. The system has the potential for 38 metered service connections. Although no commercial services are currently provided, the community has plans to construct a recreational vehicle (RV) park and convenience store in the area.

5.1.1 Source Water Supply Wells

Spider Mound #1 is the active well located adjacent to State Highway 77 (Figures 5-1 and 5-2). The well is constructed of 8-inch steel casing that extends to a depth of 865 feet bgs, whereupon the well has an open-hole completion to approximately 990 feet bgs. The well intake interval between 775 and 865 feet bgs consist of shot perforation in the steel casing. The intake is open-hole thereafter (Table 3-3).

An exploratory boring was drilled to 1,800 feet bgs; but was later backfilled to develop the most productive zone within the D-aquifer. The well is equipped with a 15-horsepower (hp) submersible pump with 13-gpm capacity. The surface completion includes a pitless adaptor unit and a high quality sanitary seal that is properly vented.

Spider Mound #2 is the inactive well located approximately 1.5 miles east of the first well. The well is constructed of 12-inch steel casing that extends to a depth of 725 feet bgs, whereupon the well has a 6-inch screen set from 735 to 835 feet bgs (Table 3.3). This well is also completed within the most productive zone within the D-aquifer. The well is equipped with similar submersible pump, and completed at the surface with a high quality sanitary seal that is properly vented.

Meter readings indicate that the daily water usage from Spider Mound #1 averaged about 2,200 gallons per day (gpd) for the period of January 2003 through mid-June 2005. This is equivalent to pumping approximately 1.5 gpm continuously from the D-aquifer.

5.1.2 Administrative Protection and Source Water Delineation

Figure 5-1 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well. Surface topography indicates that surface water drainage is primarily toward the south. The Navajo-Hopi partition land boundary is located less that one mile to the north or upgradient of Spider Mound #1. Although currently land use activities are limited to livestock grazing, the community may have difficulty controlling future land use activities on the Navajo side of the boundary. The two administrative protection zones overlap forming one area in which the community should control potential contaminating activities.

Figure 5-2 shows the aerial base with modeled groundwater capture zones, and the potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction of a numerical groundwater model for the Spider Mound area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. For source water delineation purposes, the inactive Spider Mound #2 was assumed to have a well pumping schedule similar to Spider Mound #1 through the year 2055, although it currently appears that the excess capacity of the second well will not be required for several years.

The 10- and 50-year time of travel (TOT) particle tracking pathlines are shown on Figure 5-2. The 50-year capture zone width is approximately 640 feet (320-foot radius) for both supply wells. The well spacing is sufficient to avoid pumping interferences. The maximum drawdown in the immediate vicinity of the wells is approximately 20 feet in the year 2055.

5.1.3 Contamination Source Inventory

On June 13, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The area was designated as a rural, low-density (less than 50 people) residential area, which commonly is associated with low susceptibility to sources of contamination.

Table 5-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 5-1. The identified PSOCs are of low to medium risk. The protection zones contain active animal rangeland (ARL) areas as evidenced by scattered, low concentrations of livestock waste. There is a trailer located within 500 feet of Spider Mound #1 that uses a septic tank/drain field system (RMS). The close proximity of Spider Mound #1 to State Highway 77 poses a spill risk (IUR). Fluoride, a naturally occurring inorganic (NOI), within the D-aquifer poses a long-term health risk to consumers if untreated. Finally, an abandoned well construction staging area (CCY) located in close proximity to Spider Mound #2 was identified that contained waste oils and lubricants.

A review of records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

5.1.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 5-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. As mentioned earlier, fluoride concentrations within the D-aquifer source water can naturally exceed the MCL. Total coliform, an indicator of potential microbial contamination, has been detected in the distribution system three times since construction of the PWS in the early 1990s.

Table 5-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. Consumer confidence reports (CCRs) are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Spider Mound PWS has failed to collect water samples for routine monitoring as required by the SDWA, and has failed on at least two occasions to provide CCRs. Monitoring for all regulated contaminant groups was due by December 31, 2005. Compliance with the CCR rule has been achieved since July 2001.

ED_005149_00040842-00029

5.1.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 5-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more likely the drinking water source is susceptible to contamination. For the Hopi SWA, source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Spider Mound #1 resulted in cumulative score of 16 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Low population density and limited adjacent land uses indicate that the probability of contamination from septic waste and household or commercial chemicals is low.
- Contaminant concerns are moderate with the exception of the potential for toxic substances spills from tanker trucks traveling the State Highway 77 corridor. The probability of such a spill on this straight, unobstructed stretch of road is relatively low.
- With the exception of the accidental spill scenario, the identified PSOCs are from non-point sources located within both the administrative protection and modeled capture zone.
- Lithologic data indicate that the source water is protected by approximately 400 feet of low permeability Mancos Shale that will likely impede downward contaminant migration.
- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. The inspected surface completion and reported annular cement seal to 865 feet bgs reduces this threat to a low risk. There is positive drainage away from the well.

The susceptibility analysis for Spider Mound #2 resulted in cumulative score of 13 (low risk). The factors affecting susceptibility to groundwater contamination are as follows:

- Low population density and limited adjacent land uses indicate that the probability of contamination from septic waste and household or commercial chemicals is low.
- Contaminant concerns are moderate due to type and amount. With the exception of the abandoned materials from well drilling operations, the identified PSOCs are from nonpoint sources located within both the administrative protection and modeled capture zone.
- Lithologic data indicate that the source water is protected by approximately 400 feet of low permeability Mancos Shale that will likely impede downward contaminant migration.

ED_005149_00040842-00030

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. The inspected surface completion and reported annular cement seal to 865 feet bgs reduces this threat to a low risk. There is positive drainage away from the well.

5.2 KEAMS CANYON

Keams Canyon (PWSID #090400054) PWS provides service from the junction of State Highway 264 and the Low Mountain Road to the community of Keams Canyon located approximately 8-miles to the east (Figure 3-1). The PWS consists of two N-aquifer wells, a booster pump station, two finished water storage tanks, 8-inch ductile iron transmission mains, and a distribution system within Keams Canyon. Water is gravity fed from the storage tanks to the Keams Canyon distribution system that is equipped with several pressure reducing valves to control system pressures.

The system provides approximately 142 active service connections including a BIA boarding school, police station, post office, IHS offices, several tribal businesses, and approximately 100 residences (Cadmus, 2003). The BIA Keams Canyon Agency operates and maintains the system.

5.2.1 Source Water Supply Wells

Keams Canyon #2 is located adjacent to the Low Mountain junction booster station within a locked fenced area (Figure 5-3). The well is constructed of 8-inch steel casing that extends to a depth of 906 feet bgs, whereupon the well has a 6-inch perforated interval from 906 to 1,106 feet bgs (Table 3-3). Meter readings indicate that the daily water usage from Keams Canyon #2 averaged about 48,600 gallons per day (gpd) for the period of August 2003 through mid-May 2005. This is equivalent to pumping approximately 34 gpm continuously from the groundwater source (Appendix B).

Keams Canyon #3 is located in a locked fenced area along the Low Mountain road approximately 1,000 feet north of Keams Canyon #2. The well is constructed of 8-inch steel casing that extends to a depth of 1,090 feet bgs. The perforated interval spans 931 to 1,090 feet bgs (Table 3-3). Meter readings indicate that the daily water usage from Keams Canyon #3 averaged about 20,100 gallons per day (gpd) for the period of August 2003 through April 2005. This is equivalent to pumping approximately 14 gpm continuously from the groundwater source.

Both wells were rehabilitated in 2002 when new surface casing, check valves, pitless adaptor units, and submersible pumps were installed. The new pumps are of unknown horsepower but have capacities in the 75- to 80-gpm range. Both wells have high quality sanitary seals and are properly vented. Pumped groundwater is conveyed to a concrete reservoir directly below the booster station prior to being pumped into the 8-inch water transmission main heading toward Keams Canyon. A "Keams Canyon #1" supply well does not exist – the booster station may have been originally identified as the #1 source.

Meter readings obtained during the field surveys and the annual groundwater withdrawals as reported by the USGS are provided in Appendix B. The USGS values are reported in acre-feet per year (ac-ft/yr) and vary considerably from year-to-year depending on whether Keams Canyon #2, Keams Canyon #3, or the

ED_005149_00040842-00031

combined pumping total was recorded. The USGS makes no distinction regarding which wells are included in the groundwater withdrawal totals provided in their annual monitoring reports for the Black Mesa area.

5.2.2 Administrative Protection Zones and Source Water Delineation

Figure 5-4 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well. The topography indicates that surface water drainage is primarily toward the southwest near the wells. The two administrative protection zones almost entirely overlap due to the proximity of the wells. The southern third of the Keams Canyon protection zone area overlaps with the Hopi High School protection zones.

Figure 5-5 shows the aerial base with modeled groundwater capture zones, and the potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the First Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment.

The 10- and 50-year time of travel (TOT) particle tracking pathlines are shown on Figure 5-5. The wells effectively form one groundwater capture zone due to their proximity to one another. The combined 50-year TOT capture zone width is approximately 4,400 feet wide (a 2,200 foot radius centered between the two wells) perpendicular to the direction of groundwater flow. In the immediate vicinity of the wells, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 250 feet by the year 2055. Further, predicted drawdown from pre-development conditions is approximately 175 feet by the year 2055 in the administrative protection areas defined for the Keams Canyon and Hopi High School well fields (Figure 5.4).

5.2.3 Contamination Source Inventory

On May 17, 2005, Tetra Tech completed the field survey with the assistance of a BIA maintenance worker/water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The area was designated as a rural, medium density (less than 100 people) residential area, which commonly is associated with low to medium susceptibility to sources of contamination.

Table 5-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 5-4. Keams Canyon #2 has six identified PSOCs and Keams Canyon #3 has two PSOCs of low to medium risk. Identified PSOCs within the 50-year groundwater capture zone include spill risk along State Highway 264 or the Low Mountain road (IUR), a road materials storage area (MHM), sewer lines (MSL), approximately 25 residential septic systems (RMS), and small dryland

ED_005149_00040842-00032

farming areas (AFN). Arsenic, a naturally occurring inorganic (NOI) present in the area, may pose a long-term health risk to consumers if untreated.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

5.2.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 5-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. As mentioned earlier, arsenic concentrations within the N-aquifer source water naturally exceed the new MCL effective January 2006. Cadmium and lead have both been detected above their respective MCL values, once, in the distribution system probably as the result of pipe corrosion. Total coliform, an indicator of potential microbial contamination, has been detected in the distribution system 15 times since 1996 probably has a result of inadequate system disinfection. Fecal coliform was detected once in 1997.

Table 5-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Keams Canyon PWS has failed to collect water samples for routine monitoring as required by the SDWA, and has failed on at least four occasions to provide consumer confidence reports (CCRs). Monitoring for all regulated contaminant groups, except radionuclides, was due by December 31, 2005. Compliance with the CCR rule remains a problem for this PWS.

5.2.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 5-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provides an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more likely the drinking water source is susceptible to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Keams Canyon #2 resulted in cumulative score of 23 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

ED_005149_00040842-00033

- Adjacent land use consists of a medium residential population density using septic systems. The probability of contamination from septic waste and household or commercial chemicals is considered medium due to proximity to the wellhead.

- Contaminant concerns are low with the exception of the potential for toxic substances spills from tanker trucks traveling the State Highway 264 corridor. The probability of such a spill near the Low Mountain junction is relatively low.

- With the exception of the accidental spill scenario, the identified PSOCs are from nonpoint sources located within both the administrative protection and modeled 50-year capture zone.

- Lithologic data indicate that the source water is protected by approximately 150 feet of low permeability Mancos Shale, the D-aquifer, and about 100 feet of low permeability Carmel Formation that confines the underlying N-aquifer. This stratigraphic section will significantly impede any downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. The inspected surface completion and reported annular cement seal to 926 feet bgs reduces this threat to low risk. There is positive drainage away from the well; however, the overall integrity of the cement seal is uncertain and has been questioned in the past (DBS&A, 1998).

- Naturally occurring arsenic concentrations have been measured as high as 0.046 milligrams per liter (mg/L) or over four times the new arsenic MCL. Documented casing holes, cracks, and segments with poor annular cement seals may allow poor quality from the D-aquifer to affect the quality of water produced from the N-aquifer. However, recent geochemical studies (Lopes, 1997 and Truini, 2003) indicate that as the Navajo Sandstone thins eastward from the Second Mesa area, natural mixing between the D- and N-aquifers occurs and has a pronounced affect on water quality. The source of dissolved arsenic is likely from overlying fine-grained sediments but this has not been definitively determined.

The susceptibility analysis for Keams Canyon #3 resulted in cumulative score of 14 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Low population density and limited adjacent land uses indicate that the probability of contamination from septic waste and household or commercial chemicals is low.

- Contaminant concerns are low due to potential types and amounts identified, with the exception of a potential hazardous spill along the highway. The PSOCs are from nonpoint sources located within both the administrative protection and modeled capture zone.

- Lithologic data indicate that the source water is protected by approximately 150 feet of low permeability Mancos Shale, the D-aquifer, and the underlying 100 feet low permeability Carmel Formation that confines the underlying N-aquifer. The overlying stratigraphic section will likely impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. The well is located in a small swale or depression that could allow fluid ponding around the wellhead. No well logs are available to determine the depth of the annular cement seal.

ED_005149_00040842-00034

- Naturally occurring arsenic concentrations have been measured as high as 0.035 mg/L, or over three times the new arsenic MCL. The source of dissolved arsenic is likely overlying fine-grained sediments but this has not been definitively determined.

5.3 HOPI HIGH SCHOOL

The Hopi High School (PWSID# 090400395) PWS service area is located southeast of the Low Mountain Road junction with State Highway 264 (Figure 3-1). The system is comprised of three N-aquifer wells (two in service), one elevated storage tank, one buried storage tank, a 4- to 6-inch PVC distribution system, and a reverse osmosis (RO) treatment plant for removal of high total dissolved solids (TDS) from the source water. The supply wells were constructed in the mid-1980s, and the RO treatment plant was built in the late 1990s to resolve the persistent high TDS problem.

There are approximately 48 service connections that provide water to about 40 housing units (150-200 residents), 760 high school students and 225 staff, and a community college. The school is owned by BIA but operated under contract by the Hopi Tribe (Cadmus, 2004).

5.3.1 Source Water Supply Wells

Hopi High School (HHS) #1 is located in the fenced maintenance yard compound adjacent to the 250,000-gallon pedestal storage tank. The well is constructed of 8-inch steel casing that extends to a depth of 925 feet bgs, whereupon the well has an open-hole completion to approximately 1,066 feet bgs. A TDS content of approximately 1,400 milligrams per liter (mg/L) prevents the well from being used except in emergency situations because the well pumps directly into the distribution system without RO treatment. The well is equipped with a 100-gpm submersible pump, and completed at the surface with a non-vented sanitary seal and pitless adaptor unit (Cadmus, 2004). This well is considered inactive for source water assessment purposes.

HHS #2 is located north of the school facilities in an unsecured area adjacent to the RO treatment building and the water main that conveys treated water to the distribution system. The well is constructed of 8-inch steel casing extending to a depth of 918 feet bgs, whereupon the well has an open-hole completion to approximately 1,088 feet bgs. Groundwater is pumped to the adjacent RO treatment building. The well is equipped with an 80-gpm submersible pump, and completed at the surface with a non-vented sanitary seal and pitless adaptor unit. This is the primary well supplying the High School with drinking water. The period of operation is limited by the RO treatment plant capacity and school demand. Based on available information, Tetra Tech assumed that this well is in operation on average 12-hours a day, which equates to an equivalent pumping rate of 28 gpm continuously from the N-aquifer.

HHS#3 is located in an unsecured area approximately 1,700 feet northeast of HHS#2 (Figure 5-6). The well is constructed of 8-inch steel casing that extends to 848 feet bgs; whereupon a 6-inch perforated steel casing extends from 848 to 1,048 feet bgs. The well is equipped with a 100-gpm submersible pump, and completed at the surface with a non-vented sanitary seal and pitless adaptor unit (Cadmus, 2004).

ED_005149_00040842-00035

According to the water operator, the pump discharge rate is regulated to provide only 38-gpm to the RO treatment building. The well serves in a backup capacity to HHS#2, and typically operates seven to eight hours a day or the equivalent pumping rate of 12 gpm continuously from the N-aquifer. However, at the time of the field survey the well had been inactive for approximately seven months.

5.3.2 Administrative Protection and Source Water Delineation

Figure 5-4 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well. The topography indicates that surface water drainage is primarily toward Keams Canyon Wash located to the north of the school. The three administrative protection zones overlap significantly due to the proximity of the wells. The Hopi High School protection zones are also incorporated in the Keams Canyon protection zones to the north.

Figure 5-6 shows the aerial base with modeled groundwater capture zones, and the potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the First Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were held constant at current levels in groundwater modeling projections reflecting the current capacity of the RO water treatment plant and Hopi High School. Tetra Tech assumed that future water demand will be met by water sources other than the current well field due to high RO operational cost.

The 10- and 50-year time of travel (TOT) particle tracking pathlines are shown on Figure 5-6. The wells effectively form one groundwater capture zone due to their proximity to one another. The combined 50-year TOT capture zone is approximately 3,000 feet perpendicular to the direction of groundwater flow, and 4,700 feet in the direction of groundwater flow. In the immediate vicinity of the wells, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 220 feet by the year 2055. Further, predicted drawdown from pre-development conditions is approximately 175 feet by the year 2055 in the administrative protection areas defined for the Keams Canyon and Hopi High School well fields (Figure 5.4).

5.3.3 Contamination Source Inventory

On May 19, 2005, Tetra Tech completed the field survey with the assistance of the water operator. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The area was designated as a rural, medium to high-density (greater than 100 people) residential/municipal area, which commonly is associated with a medium susceptibility to sources of contamination.

Table 5-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 5-4. The supply wells were not separated for identification of PSOCs due to the inactive status of HHS#1 and the close proximity of the two active wells (HHS#1 and #2). A total of nine PSOCs of low to medium risk were identified.

ED_005149_00040842-00036

PSOCs within the 50-year groundwater capture zone include maintenance yard (MSC-1) and buildings associated with school operations and chemical storage (MSC-2), the RO brine disposal lagoon (MWP), sports fields (MPR-1 and -2), and naturally occurring inorganic (NOI) arsenic.

Review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

5.3.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 5-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. Arsenic concentrations within the N-aquifer source water naturally exceed the new MCL effective January 2006. Measured arsenic concentrations have ranged from 0.013 to 0.034 mg/L for the untreated source water. The untreated source water also exceeds the aesthetic secondary standards for fluoride, chloride, and TDS. The brackish nature of the water has been attributed to mixing of N- and D-aquifers (DBS&A, 1993b).

In 2001, a sample of RO treated water had an arsenic concentration of 0.016 mg/L which exceeds the new arsenic standard (0.010 mg/L). In 1998, lead concentrations within the distribution system were detected above the MCL value indicating corrosion issues with the older distribution piping. Total coliform, an indicator of potential microbial contamination, has been detected in the distribution system 23 times since 1996, probably has a result of inadequate system disinfection.

Table 5-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Hopi High School PWS failed to collect water samples for routine monitoring of nitrate and dioxin as required by the SDWA, and failed to provide a consumer confidence report (CCRs) in 2004. Monitoring for nitrate was due by December 31, 2005. The next sampling due date for IOCs, SOCs,and VOCs is December 31, 2007 (Appendix D).

The Hopi Tribe and USGS have completed several studies that investigated supply wells that produce groundwater of higher salinity than others in the vicinity. The Hopi High School wells yield groundwater with higher than normal salinity for the N-aquifer. Although these wells yield large quantities of groundwater, the natural water is considered undesirable for human consumption due to the brackish nature of the water, and requires treatment by RO.

ED_005149_00040842-00037

5.3.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 5-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number, the greater the susceptibility to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for the Hopi High School supply wells resulted in cumulative score of 21 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density that uses a sanitary sewer system. The probability of contamination from septic waste and household or commercial chemicals is considered low.

- Contaminant concerns, with the exception of chemical supplies stored in the maintenance yard near HHS#1, are low. Potential non-point sources associated with the sporting fields are also considered to be low risk. Sewage and brine lagoons are outside of the 50-year TOT for groundwater capture by the well field.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 150 feet of low permeability Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will likely impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. Well surface completions coupled with the lack of information on annular cement seals adequacy makes this possibility a medium risk. There is positive drainage away from wells HHS#2 and #3; however, the overall integrity of the cement seals have been questioned in the past (DBS&A, 1993a) and the possibility exists for water ponding around the HHS#1 wellhead.

- Naturally occurring arsenic concentrations have been measured as high as 0.034 mg/L or over three times the new arsenic MCL. Poor annular cement seals may allow poor water quality from the D-aquifer to affect the quality of water produced from the N-aquifer. However, recent geochemical studies (Lopes, 1997 and Truini, 2003) indicate that as the Navajo Sandstone thins eastward from the Second Mesa area natural mixing between the D- and N-aquifers has a pronounced affect on water quality. The source of dissolved arsenic is likely from overlying fine-grained sediments but this has not been definitively determined.

5.4 POLACCA/FIRST MESA CONSOLIDATED VILLAGES

The Polacca PWS (PWSID# 090400106) serves residential areas along the base and on top of First Mesa (Figure 5-3). The system is comprised of two active N-aquifer supply wells, one emergency N-aquifer supply well, three storage tanks, two booster pumping stations, and the distribution system.

ED_005149_00040842-00038

Groundwater is pumped from the wells to storage tanks that allow the majority of the distribution system to be served by gravity flow. A sequence of booster stations transfers water to the distribution system located on top of the mesa. Looping of the distribution system and multiple pressure reducing stations provide adequate water circulation with the possible exception of along the far northern and eastern ends of the system (Cadmus, 2004).

The system serves an estimated population of 3,240 persons on a year-round basis (IHS, 2005). PWS administration, system components, well construction, and aquifer characteristics can be found in Tables 3-1 through 3-3.

5.4.1 Source Water Supply Wells

Polacca #5 is an active supply well located in an unsecured area near the western end of the PWS adjacent to State Highway 264 (Figures 5-7 and 5-8). The well was constructed in the mid-1980s, and consists of 10-inch steel casing to 645 feet, 8-inch steel casing from 635 to 775 feet, and 8-inch perforated steel casing from 775 to 915 feet bgs. The well is reportedly equipped with a 100-gpm submersible pump, and the surface completion consists of a pitless adapter unit with a high quality vented sanitary seal. Daily water usage averaged about 77,900 gpd for the first six months of 2005. Annual groundwater withdrawals as reported by the USGS are in general agreement with 2005 usage, although their monitoring reports make no distinction between which wells are included in the groundwater withdrawal total for the area. The water demand is equivalent to pumping approximately 54-gpm continuously from the groundwater source (Appendix B).

Polacca #6 is an inactive supply well located in an unsecured location approximately 500 feet northeast of Polacca #5 (Figure 5-8). The well was also constructed in the mid-1980s, and consists of 10-inch steel casing to 647 feet, 8-inch steel casing from 635 to 775 feet, and 8-inch perforated steel casing from 775 to 915 feet bgs. The well is equipped with a submersible pump of unknown capacity, and the surface completion consists of a pitless adapter unit with a high quality vented sanitary seal. TDS, sulfate, and chloride concentrations exceeded aesthetic secondary water quality standards and prevent the well from being used except in emergency situations. The well is considered inactive for source water assessment purposes as emergency pumping is considered a minimal aquifer stress.

Polacca #8 is an active supply well located in an unsecured area near the northeastern end of the PWS. The well was constructed in the late 1990s, and consists of 12-inch steel casing cemented in place to 900 feet bgs and a 6-inch screened interval spanning 900 to 1,100 feet bgs. The well is equipped with a 110-gpm submersible pump, and the surface completion consists of a pitless adapter unit with a high quality vented sanitary seal. Daily water usage averaged about 69,200 gpd for the first six months of 2005. Annual groundwater withdrawals as reported by the USGS are in general agreement with 2005 usage, although USGS monitoring reports make no distinction between which wells are included in the groundwater withdrawal total for the area. The water demand is equivalent to pumping approximately 48-gpm continuously from the groundwater source (Appendix B).

5.4.2 Administrative Protection and Source Water Delineation

Figure 5-7 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well. The topography indicates that surface water drainage is primarily toward Polacca Wash located to the southeast of the active wells. The Polacca #5 and #6 administrative protection zones overlap almost completely due to the close proximity of the wells. The Polacca #8 protection area is located north of the main population centers.

Figures 5-8 and 5-9 show the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for Polacca #5 and #8, respectively. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the First Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The theoretical maximum pumping rate for Polacca #5 and #8 are reached during years 2022 and 2035, respectively.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for Polacca #5 are shown on Figure 5-8. The 50-year TOT capture zone width is approximately 3,900 feet (1,950-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 265 feet by the year 2055.

The 10- and 50-year TOT particle tracking pathlines for Polacca #8 are shown on Figure 5-9. The 50-year TOT capture zone is approximately 3,700 feet (1,850-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 300 feet by the year 2055.

The predicted drawdown from pre-development conditions is approximately 150 feet by the year 2055 in the overall administrative protection area roughly defined by the two production wells.

5.4.3 Contamination Source Inventory

On May 18, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as medium to high-density (more than 100 people) residential areas, with limited commercial and municipal government activities. This designation is commonly associated with low to medium susceptibility to sources of contamination. Low-density housing is present near the supply wells, and with majority of adjacent lands located within the 50-year TOT groundwater capture zone is rural and pristine.

ED_005149_00040842-00040

Table 5-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 5-8. A total of 11 PSOCs were identified within the Polacca #5 administrative protection zone. Field ranked potential risk factors range from low to medium. Within the 50-year TOT capture zone, there were four PSOCs identified of which three were considered medium risk primarily due to proximity to the well. PSOCs within the 50-year TOT capture zone include State Highway 264 tanker truck spill hazard (IUR/MHM), sanitary sewer lines and abandoned residential septic systems near the well head (MSL/RMS), two gravel pits located west of the well (IMO), and naturally occurring inorganic (NOI) arsenic present in the area.

A total of 11 PSOCs were identified within the Polacca #8 administrative protection zone. Field ranked potential risk factors range from low to medium. Within the 50-year TOT capture zone subset there were two PSOCs identified of which one was considered medium risk. PSOCs within the 50-year TOT capture zone include sanitary sewer lines and potentially scattered home site on septic systems (MSL) and naturally occurring inorganic (NOI) arsenic present throughout the area.

As the well numbering suggests, the PWS used other groundwater sources in the past that are no longer in use. Four shallow wells northwest of Polacca #5 and adjacent to Wepo Wash have been abandoned due to nitrate concentrations that exceed the maximum contaminant level (MCL) value (Cadmus, 2004). Another former supply well located next to the now inactive Polacca Day School is no longer in service. The location of the well identified by Tetra Tech during the field surveys are posted on Figure 5-7. Although these wells are at or outside of the active supply well administrative boundaries, they should nonetheless be properly abandoned to eliminate conduits for potential contamination that can quickly migrate into the source water supply.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

5.4.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 5-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. Polacca #6 has exceeded the primary MCL for fluoride an indication of D-aquifer source water contributions. In 2000, lead concentrations at three locations within the distribution system were detected above the MCL indicating corrosion issues with the older distribution piping. Total coliform, an indicator of potential microbial contamination, has been detected in the distribution system 19 times since 1996, probably as a result of inadequate system disinfection.

Arsenic concentrations within the source water naturally exceed the new MCL effective January 2006. Measured arsenic concentrations have ranged from below detection limits of 0.001 mg/L to 0.022 mg/L for the three source water wells. Large variations in arsenic and fluoride concentrations are apparent in the data set between wells and sampling events at the same location (e.g. Polacca #6 arsenic concentrations have ranged from less than 0.001 mg/L to 0.017 mg/L, see Appendix D).

ED_005149_00040842-00041

The relative contributions of poor quality water are likely correlated with the daily pumping schedule as the length of pumping will affect source water contributions from the D-aquifer.

Table 5-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Polacca/FMCV PWS failed to collect water samples for routine monitoring of nitrate and dioxin as required by the SDWA, and failed to provide a consumer confidence report (CCRs) in 2004. Routine monitoring for all contaminant groups except radionclides were due by December 31, 2005 (Appendix D).

5.5.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 5-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Polacca #5 resulted in cumulative score of 17 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density with a sanitary sewer system. The probability of contamination from septic waste and household or commercial chemicals is considered low as old septic systems upgadient of the well are no longer in use.

- Contaminant concerns, with the exception of potential for chemical spills along State Highway 264, are considered low. Potential non-point sources associated with limited gravel operations are also considered to be of low risk. Sewage lagoons are located downgradient and outside of the 50-year TOT for groundwater capture by the well.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 200 feet of low permeability Mancos Shale, the D-aquifer, and another 100 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. There is positive drainage away from well; however, the overall integrity of the

ED_005149_00040842-00042

cement seal is poor and the well intake was completed across the D- and N-aquifer allowing a direct connection between the two water sources.

- Naturally occurring arsenic has been measured as high as 0.020 mg/L at Polacca #5, or twice the new arsenic MCL. The well completion allows poor water quality from the D-aquifer to mix with water produced from the N-aquifer. The source of dissolved arsenic is likely from overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

The susceptibility analysis for Polacca #8 resulted in cumulative score of 11 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density that uses a sanitary sewer system. The probability of contamination from septic waste and household or commercial chemicals is considered low.

- Contaminant concerns are negligible. Sewage lagoons are located downgradient and outside of the 50-year TOT for groundwater capture by the wells.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 200 feet of low permeability Mancos Shale, the D-aquifer, and another 100 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will likely impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. Although, this well was completed in accordance to the Hopi Water Code pressure cementing requirements and observed by Hopi WRP technicians during construction. There is positive drainage away from well.

- Naturally occurring arsenic concentrations have been measured as high as 0.022 mg/L at Polacca #8 or twice the new arsenic MCL. Although water quality issues associated with high TDS, fluoride, and chloride have been eliminated through more protective well installation techniques there appears to be sufficient hydraulic connection with fine-grained sediments containing dissolved arsenic to present a long-term health risk.

ED_005149_00040842-00043

6.0 SECOND MESA SOURCE WATER ASSESSMENTS

This section describes the source water assessments completed for PWSs that serve the Second Mesa area (Table 1-2). For each PWS, the discussion includes information on (1) general system operation, (2) source water delineation, (3) contamination source inventory, and (4) susceptibility analysis. The PWS descriptions draw from the most recent sanitary surveys completed by Cadmus (2003 and 2004).

Information on PWS administration, system components, well construction, and aquifer characteristics are provided in Tables 3-1 through 3-3. Figure 6-1 shows the location of the various PWSs serving the Second Mesa area.

6.1 LOWER SIPAULOVI

Sipaulovi PWS (PWSID# 090400107) serves residential areas along the eastern base of Second Mesa near the intersection of State Highways 264 and 87 (Figures 3-1 and 6-1). Residential areas include the Lower Sipaulovi subdivision, the Lower Mishongnovi housing areas located to the east along State Highway 264, and various scattered housing units throughout area. The system consists of one N-aquifer well, a 75,000-gallon storage tank, and a gravity-fed distribution system. The distribution system is connected with the BIA Second Mesa PWS allowing emergency service, as needed. From the storage tank, water travels through an 8-inch diameter asbestos concrete (AC) pipe that transitions to (1) C900 8-inch diameter PVC pipe to service the eastern area, and (2) 6-inch AC pipe to service the southern area.

The system serves an estimated population of 535 persons and seven-businesses on a year-round basis.

6.1.1 Source Water Supply Wells

Lower Sipaulovi #1 is an active supply well located in a secured area immediately north of the junction of State Highways 264 and 87 (Figures 6-1 and 6-2). The well was constructed in 1978, and consists of 8-inch steel casing to 700 feet, 6-inch steel casing from 674 to 700 feet, and 6-inch perforated casing from 700 to 983 feet bgs. The well is equipped with an 85-gpm submersible pump, and the surface completion consists of a vented and sealed well casing extending above the concrete base of the pump house. Although the pump house does not contain a floor drain, water effectively drains away from the casing between the interface of a new concrete floor and the old floor near the pump house walls (Cadmus, 2003).

Daily water usage averaged about 14,100 gallons per day (gpd) for period of November 2004 through June 2005. Annual groundwater withdrawals as reported by the USGS indicate that water usage has declined from a peak usage of 40.7 ac-ft/year in 1996 to about 20 ac-ft/year at present, or about half of the measured peak usage. The water use reduction is likely due to closure of several businesses near the junction of State Highways 264 and 87. A long-term water usage average of 24.7 ac-ft/year was used for the groundwater capture zone modeling. This water demand is equivalent to pumping approximately 15.3-gpm continuously from the groundwater source (Appendix B).

ED_005149_00040842-00044

6.1.2 Administrative Protection and Source Water Delineation

Figure 6-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located on the southeastern side of Second Mesa. The topography near Lower Sipaulovi #1 indicates that surface water drainage is primarily toward the south. There is substantial administrative protection zone overlap with supply wells supporting other local PWSs (see Sections 6.2 and 6.3) due to the close proximity of the wells. There are three, relatively low production, supply wells (Second Mesa Day School [SMDS] #1and #2 (Section 6.2), and Mishongnovi-Sipaulovi #1Section 6.3)) within 1-mile of Lower Sipaulovi #1 supply well. Toreva, and the Villages of Sipaulovi and Mishongnovi are located north and upgradient of the well.

Figure 6-3 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for Lower Sipaulovi #1 and SMDS #1. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for Lower Sipaulovi #1 are shown on Figure 6-3. The 50-year TOT capture zone width is approximately 1,730 feet (865-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 72 feet by the year 2055.

The predicted drawdown from pre-development conditions is approximately 36 feet by the year 2055 in the overall administrative protection area defined by the supply wells shown on Figure 6-2. The modeling results are in general agreement with other recent estimates for the Second Mesa area (DBS&A, 2003).

6.1.3 Contamination Source Inventory

On June 14, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as medium to high-density (more than 100 people) residential areas, with limited commercial and municipal government activities. This designation is commonly associated with low to medium susceptibility to sources of contamination. Adjacent lands located within the 50-year TOT groundwater capture zone are rural and pristine.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 6-2. A total of 16 PSOCs were identified within the Lower Sipaulovi #1 administrative protection zone, of which 2 are within the 50-year TOT capture zone.

ED_005149_00040842-00045

Field ranked potential risk factors range from low to medium. Within the 50-year TOT capture zone, there were two PSOCs identified: (1) dryland farming activities (AFN) and (2) naturally occurring inorganic (NOI) arsenic present in the area. The naturally occurring arsenic constitutes a medium risk due to long-term potential health threat.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

6.1.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. Lower Sipaulovi #1 has exceeded the primary MCL for total coliform, an indicator of potential microbial contamination, once in the distribution system since 1996. Arsenic concentrations within the source water naturally exceed the new MCL effective January 2006. The maximum arsenic concentration (0.024 mg/L) was measured in 2002.

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Sipaulovi PWS has achieved compliance with monitoring requirements but typically after the sampling due dates. An exception is the monitoring for dioxins, which appears to remain an outstanding deficiency. The consumer confidence report (CCRs) is current as of 2004. Routine monitoring for all contaminant groups except radionclides and asbestos were due by December 31, 2005 (Appendix D). Past asbestos measurements have all been below the detection level.

6.1.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15, medium for sums between 16 and 30, and high for sums greater than 30.

ED_005149_00040842-00046

The susceptibility analysis for Lower Sipaulovi #1 resulted in cumulative score of 10 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density with a sanitary sewer system. The probability of contamination from septic waste and household or commercial chemicals is considered low.

- Contaminant concerns are considered low. One sewage lagoon is located upgradient of the well; however, it is outside of the 50-year TOT for groundwater capture by the well.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 250 feet of low permeability Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. There is positive drainage away from well and there is a reported cement annular seal extending to 697 feet bgs; however, the overall integrity of the cement seal is unknown.

- Naturally occurring arsenic has been measured at a maximum concentration of 0.024 mg/L at Lower Sipaulovi #1, or over twice the new arsenic MCL. The source of dissolved arsenic is likely from overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

6.2 SECOND MESA DAY SCHOOL

The inactive Second Mesa PWS (PWSID #09000061) served approximately 180 students and 40 employees at the Second Mesa Day School (SMDS) prior to school expansion activities currently underway. Old school facilities have been demolished to make room for construction of a larger school that will serve 350 students and provide 20 residential units for school staff (Plateau 2005). The SMDS site is located immediately west of the junction of State Highways 264 and 87 (Figure 3-1).

The PWS consists of one designated N-aquifer well, a 50,000-gallon storage tank, and a gravity-fed distribution system. The system has emergency water distribution connections with the inactive Toreva PWS (PWSID #090400055) and the Lower Sipaulovi PWS (Figure 6-1). Several water system improvement alternatives have been evaluated for the Second Mesa PWS that remain under consideration for providing water to the new school and surrounding community (Plateau 2002 and 2005). Each alternative includes plans for consolidation of existing water sources through abandonment of deteriorating supply wells and construction of a new supply well that conforms to current construction standards defined in the Hopi Water Code. Two supply wells, Second Mesa Day School #1 and #2, were evaluated for the Second Mesa PWS as these wells or their replacements will likely serve the needs of the new school once completed.

ED_005149_00040842-00047

6.2.1 Source Water Supply Wells

Constructed in 1957, Second Mesa Day School #1 (SMDS #1) is one of the oldest N-aquifer wells on the Hopi Reservation. Over the years this well has provided water supply to the SMDS, the community of Toreva, and now serves as a construction water source for the new school. Use of the well for the Toreva PWS was discontinued in 2002 after leaks from deteriorating conveyance piping lead to the partial collapse of the Toreva sewage lagoon (Cadmus, 2003). The lack of alternate piping routes, line replacement costs, and cross contamination concerns have prevented repair and continued service of the relatively small community water needs in Toreva. A replacement water supply well in the SMDS #1 location is under consideration for the new school.

SMDS #1 is located in a locked pump house within the fenced boundaries of the school site (Figure 6-2). The well was constructed of 8-inch steel casing set to a depth of 648 feet bgs. Below the casing, an open-borehole completion extends to a reported depth of 850 feet bgs for access to the N-aquifer. The well was equipped with a 38-gpm submersible pump in 2002. At the surface, the well casing is surrounded by a concrete block that extends 10-inches above the pump house floor. A steel plate covers the well but does not provide an adequate sanitary seal. Meter readings are not readily available for SMDS #1 as it has been inactive since November 2002.

SMDS #2 is located in a locked pump house approximately 1,750 feet northeast of the day school (Figure 6-2). Constructed in 1968, the well consists of 8-inch steel casing to 922 feet, perforated between 740 and 860 feet, and 6-inch perforated casing extending from 922 to 1,090 feet bgs. A new 60-gpm submersible pump was installed in 2002. The well extends 9-inches above the pump house floor and is covered with a steel plate that provides an inadequate sanitary seal.

Annual groundwater withdrawals reported by the USGS for the SMDS are provided in Appendix B. SMDS water use averaged about 7.5 ac-ft/yr for the period of record of 1984 through 2003. This is equivalent to pumping approximately 4.7-gpm continuously from the groundwater source to support past school activities. Plateau (2002) has projected a future water demand of 18 ac-ft/yr for the school; however, recent water use estimates have been revised upward to account for irrigated sporting fields.

6.2.2 Administrative Protection and Source Water Delineation

Figure 6-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located on the southeastern side of Second Mesa. The topography near SMDS #1 and #2 indicates that surface water drainage is primarily toward the south. There is substantial administrative protection zone overlap for the supply wells supporting local PWSs due to the close proximity of the wells. There are two production wells, Lower Sipaulovi #1 and Mishongnovi-Sipaulovi #1, within 1-mile of the two wells that may support the Second Mesa PWS in the future. The communities of Toreva, Sipaulovi, and Mishongnovi are located upgradient of supply well SMDS #1 and #2.

ED_005149_00040842-00048

Figure 6-3 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for Second Mesa PWS. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Tetra Tech assumed that the preferred location for the new supply well will replace SMDS #1 at the school, SMDS #2 will be abandoned, and Lower Sipaulovi #1 will continue to be used in the future to support residential growth along the eastern base of Second Mesa. The pumping rate for the replacement well was held constant at 18 ac-ft/yr to account for school's projected increases in water demand.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for replacement well SMDS #1 are shown on Figure 6-3. The 50-year TOT capture zone width is approximately 1,370 feet (685-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 59 feet by the year 2055.

The predicted drawdown from pre-development conditions is approximately 36 feet by the year 2055 in the overall administrative protection area defined by the supply wells shown on Figure 6-2. The modeling results are in general agreement with other recent estimates for the Second Mesa area (DBS&A 2003).

6.2.3 Contamination Source Inventory

On June 15 and 16, 2005, Tetra Tech completed field surveys with the assistance of water operators from the Tribe and BIA, and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. Within the administrative protection area the population is clustered in medium to high-density areas (more than 100 people) that have a mix of residential, commercial, and municipal government activities. This level of activity is typically associated with low to medium susceptibility to sources of contamination. The adjacent lands located within the 50-year TOT groundwater capture zone are characterized by mixed use consisting of residential, commercial, and municipal (school) activities.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 6-2. A total of 14 PSOCs were identified within the Second Mesa PWS administrative protection zones defined by supply wells SMDS #1 and #2. Field ranked potential risk factors range from low to high. Seven of these are also located within the 50-year TOT capture zone, of which three are considered medium risk due to their proximity and location upgradient of the assumed replacement well. Medium-risk PSOCs include the former PHW Texaco (CHG/CAR) with a documented fuel release, an adjacent junkyard (CSY), and a potential spill hazard (IUR) related to commerce along State Highway 264. Finally, identified wells that no longer serve a functional purpose (SMDS #1, SMDS #2, and a well located west of the PWH Texaco) should be properly abandoned once a replacement well is constructed for the new school to eliminate conduits for potential contamination to quickly migrate into the source water supply.

Although present throughout the Second Mesa area, the concentration of naturally occurring inorganic (NOI) arsenic at the SMDS #1 location is below the new arsenic MCL. However, with increased groundwater pumping there is the potential to capture groundwater with higher concentrations of arsenic.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

6.2.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCLs for regulated chemical and radiological contaminants. The Second Mesa PWS has exceeded the primary MCL for total coliform, an indicator of potential microbial contamination, four separate times in the distribution system since 1996. Alpha emitters, a form of radiation that can increase long-term cancer risk, were detected in the distribution system above the primary MCL in 1980. Nitrate, which is commonly associated with wastewater discharges, was detected above the primary MCL in a water storage tank that is no longer in use. Arsenic concentrations within SMDS #1 source water are below the new MCL of 0.010 mg/L that is effective January 2006; however, SMDS #2 source water exceeds the new arsenic standard. Maximum arsenic concentrations of 0.003 mg/L and 0.020 mg/L have been measured at the SMDS #1 and SMDS #2 locations, respectively.

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. Consumer confidence reports (CCRs) are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Second Mesa PWS has not maintained compliance with monitoring requirements for nitrate, asbestos, and SVOCs. Further, CCRs have not been prepared on a regular basis for the Second Mesa PWS. Routine monitoring for IOCs was due by December 31, 2005 (Appendix D).

6.2.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to

ED_005149_00040842-00050

contamination. Hopi source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15, medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for the Second Mesa PWS resulted in cumulative score of 30 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density engaged in residential, light commercial, and school administration activities. Within the 50-year groundwater capture zone, wastewater is collected by a sanitary sewer system and routed to a lined sewage lagoon south of the school (downgradient). Scattered home sites east of the school use individual septic systems. The probability of contamination from septic waste and common household chemicals is considered low.

- The SMDS #1 location is vulnerable to chemical contamination from the upgradient PWH Texaco and chemical spills that may occur along State Highway 264. The overall risk is considered medium. Chemical vulnerability at the SMDS #2 is considered low because the well is located upgradient of identified contaminant concerns.

- Lithologic data for the area indicate that the N-aquifer is protected from surface pollution sources by approximately 220 feet of low permeability Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of chemical contamination along the SMDS #1 well borehole annulus or direct introduction of contaminants to the well from ground surface represents the greatest threat. SMDS #1 presently has an inadequate surface seal and relatively easy access during school construction that significantly increases vulnerability to contamination. The existence of a cement annular seal and its overall integrity (if one exists) is unknown.

- Naturally occurring arsenic has been measured at a maximum concentration of 0.020 mg/L at SMDS #2, or twice the new arsenic MCL. The source of dissolved arsenic is likely from overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

6.3 SIPAULOVI-MISHONGNOVI

The Sipaulovi-Mishongnovi PWS (PWSID #090400394) serves residential areas of the two villages built on top of the eastern most extent of Second Mesa (Figures 3-1 and 6-1). The system consists of one N-aquifer well, a 16,000-gallon storage tank, a booster pump station, and a distribution system consisting primarily of 4-inch galvanized and 2-inch PVC pipe. The system has about 40 service connections for a population of about 400 people. Many homes use water points spread throughout the older portions of the two communities because they lack indoor plumbing. The system is not interconnected with any other water systems.

ED_005149_00040842-00051

6.3.1 Source Water Supply Wells

Mishongnovi-Sipaulovi #1 is located in a locked pump house between the two villages (Figure 6-2). The well was constructed in 1979, and consists of 8-inch steel casing to 1,155 feet; 7-inch perforated steel casing from 1,155 to 1,313 feet, and an open borehole from 1,313 to 1,366 feet bgs. A new 8.5-gpm submersible pump was installed in 2002. The well casing extends 20-inches above the pump house floor and is completed with a vented sanitary seal.

Average daily water usage is estimated at 7,600 gallons per day (gpd) based on pump capacity and hours of daily operation described by the water operator. Annual groundwater withdrawals as reported by the USGS indicate that water usage has been 5.5 ac-ft/yr of greater since 1995. Summer 2005 well withdrawals equate to an annual groundwater withdrawal rate of 8.6 ac-ft/yr, in general agreement with long-term water usage trends for the system. This rate of usage provides the current conditions in the groundwater capture zone modeling. Estimated current demand is equivalent to pumping approximately 5.3-gpm continuously from the groundwater source (Appendix B).

6.3.2 Administrative Protection and Source Water Delineation

Figure 6-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located on the southeastern side of Second Mesa. Mishongnovi-Sipaulovi #1 is situated on a topographic divide with surface flows draining either to the south or east from the well site. There is substantial administrative protection zone overlap with the supply wells that support other PWSs located below the mesa top (Sections 6.1 and 6.2).

Figure 6-4 shows the aerial base with the modeled groundwater capture zone and potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The theoretical maximum pumping rate for Mishongnovi-Sipaulovi #1 is reached during year 2013.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for Mishongnovi-Sipaulovi #1 are shown on Figure 6-4. The 50-year TOT capture zone width is approximately 940 feet (470-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 46 feet by the year 2055.

The predicted drawdown from pre-development conditions is approximately 36 feet by the year 2055 in the overall administrative protection area defined by the supply wells shown on Figure 6-2. The modeling results are in general agreement with other recent estimates for the Second Mesa area (DBS&A 2003).

ED_005149_00040842-00052

6.3.3 Contamination Source Inventory

On June 14, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as medium- to high-density (more than 100 people) residential areas. This designation is commonly associated with low to medium susceptibility to sources of contamination. The adjacent lands located within the 50-year TOT groundwater capture zone are rural and pristine.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 6-2. A total of 10 PSOCs were identified within the Mishongnovi-Sipaulovi #1 administrative protection zone. Field ranked potential risk factors range from low to medium. Four of the 10 PSOCs are also within the 50-year TOT capture zone, and two were considered medium risk due to (1) proximity and elevation of sanitary sewer lines (MSL) and (2) naturally occurring inorganic (NOI) arsenic concentrations in the source water. The PSOCs considered to be of low risk within the 50-year TOT capture zone include high density housing (MHD) and a residential dump area (RDA).

A review of existing records maintained by the Hopi Tribe and EPA indicated that no other PSOC have been identified beyond those determined during the field survey.

6.3.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCLs for regulated chemical and radiological contaminants. There are no reported MCL exceedances for the Mishongnovi-Sipaulovi PWS. However, arsenic concentrations within the Mishongnovi-Sipaulovi #1 source water exceed the new MCL of 0.010 mg/L effective January 2006. The maximum arsenic concentration of 0.013 mg/L, which is slightly above the new arsenic standard, was measured in 2004.

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. Consumer confidence reports (CCRs) are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Mishongnovi-Sipaulovi PWS has not maintained compliance with monitoring requirements for dioxin and fluoride. Also, CCRs have not been prepared on a regular basis for the PWS. Routine monitoring for nitrate, IOCs, SOCs, and VOCs was due by December 31, 2005 (Appendix D).

6.3.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15, medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Mishongnovi-Sipaulovi #1 resulted in a cumulative score of 16 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density engaged in residential and village administration activities. Within the 50-year groundwater capture zone, wastewater is collected by a sanitary sewer system and routed to a lined sewage lagoon southwest of the well. Scattered home sites and older areas of the community are without plumbing and thus rely on outdoor privies for sanitation. The probability of contamination from septic waste and common household chemicals is considered low.

- Contaminant concerns are considered to be low because the well is located upgradient of identified contaminant concerns.

- Lithologic data area indicate that the N-aquifer is protected from surface pollution sources by approximately 600 feet of low permeability Toreva Formation and Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of chemical contamination along the well borehole annulus or direct introduction of contaminants to the well from ground surface represents the greatest threat; however, the high-quality sanitary seal and approximately 1,100 feet of cement annular seal minimize this threat.

- Naturally occurring arsenic has been measured at a concentration of 0.013 mg/L at Mishongnovi-Sipaulovi #1. The source of dissolved arsenic is likely overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

6.4 SHUNGOPAVI

Shungopavi PWS (PWSID # 090400259) serves residential areas within the village and adjacent areas along State Highway 264 (Figures 3-1 and 6-1). The system is comprised of one N-aquifer well, a 50,000-gallon storage tank, and a distribution network of 2-inch through 8-inch Schedule 40 PVC piping gravity-fed by the storage tank (Cadmus, 2004). An EPA-funded water system improvement project is currently in the design stages to address extensive system deficiencies as described in Table 3-2.

ED_005149_00040842-00054

The system currently provides water to approximately 1,500 people through 300 connections within the service area. Many residents continue to haul water from outdoor water distribution points because they lack indoor plumbing. The PWS is not interconnected with any other water systems.

6.4.1 Source Water Supply Wells

Shungopavi #1 is an active supply well located in a secured area immediately north of the main village (Figures 6-1 and 6-2). The well was constructed in 1969, and consists of 10-inch steel casing to 1,312 feet, 6-inch steel casing from 1,312 to 1,337 feet, and 6-inch perforated casing from 1,337 to 1,530 feet bgs. The well is equipped with a 56-gpm submersible pump. The surface completion consists of a vented and sealed well casing extending above ground level protected by a makeshift addition to the pump house.

In 2004, daily water usage averaged 34,000 gallons per day (gpd) or 38 ac-ft/yr based on corrected meter readings (Tetra Tech 2005). Annual groundwater withdrawals reported by the USGS are provided in Appendix B. Water use has steadily increased with growth of the community. The current water demand is equivalent to pumping approximately 24-gpm continuously from the groundwater source (Appendix B).

6.4.2 Administrative Protection and Source Water Delineation

Figure 6-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located on the southeastern side of Second Mesa. The ground surface near Shungopavi #1 slopes slightly to the west toward the edge of the mesa. There is slight administrative protection zone overlap with supply well SMDS #1 located to the southeast below the mesa top.

Figure 6-5 shows the aerial base with the modeled groundwater capture zone and potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The theoretical maximum pumping rate for Shungopavi #1 is reached during year 2038.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for Shungopavi #1 are shown on Figure 6-5. The 50-year TOT capture zone width is approximately 2,350 feet (1,175-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 82 feet by the year 2055.

ED_005149_00040842-00055

The predicted drawdown from pre-development conditions is approximately 36 feet by the year 2055 in the overall administrative protection area defined by the supply wells shown on Figure 6-2. The modeling results are in general agreement with other recent estimates for the Second Mesa area (DBS&A 2003).

6.4.3 Contamination Source Inventory

On June 14, 2005 Tetra Tech completed the field survey with the assistance of the water operator. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as a medium to high-density (more than 100 people) residential area. This designation is commonly associated with low to medium susceptibility to sources of contamination. Adjacent lands located within the 50-year TOT groundwater capture zone are entirely residential.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 6-2. A total of 12 PSOCs were identified within the Shungopavi #1 administrative protection zone, seven of which were also within the 50-year TOT capture zone. Field ranked potential risk factors range from low to medium. Of the PSOCs within the 50-year TOT capture zone, four were considered medium risk due to proximity and relative elevation, including (1) the storage and maintenance area near the well (CCY), (2) a historic gas station (CHG), (3) sanitary sewer lines (MSL), and (4) naturally occurring inorganic (NOI) arsenic concentrations in the source water. The PSOCs considered to be of low risk within the 50-year TOT capture zone include chemical spill potential along State Highway 264 (IUR), high density housing (MHD), and individual residential septic systems (RMS).

A review of existing records maintained by the Hopi Tribe and EPA indicate no other PSOC have been identified beyond those determined during the field survey.

6.4.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance(s) of established MCL values for regulated chemical and radiological contaminants. The Shungopavi PWS experienced significant problems with microbial contamination in the distribution system during the late 1990s. However, total and fecal coliform have not been detected for over four years, which is probably a result of improved water system disinfection practices. Alpha emitters, a form of radiation that can increase long-term cancer risk, were detected in the distribution system above the primary MCL in 1980. Shungopavi #1 arsenic concentrations exceed the new arsenic standard of 0.010 mg/L that is effective January 2006. In 2005, an arsenic concentration of 0.017 mg/L was measured in the source water.

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004.

ED_005149_00040842-00056

All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. Consumer confidence reports (CCRs) are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Shungopavi PWS is out of compliance for nitrate monitoring and had a poor monitoring record for other regulated contaminants until compliance was achieved in 2003. Annual CCRs compliance was also achieved in 2003. Routine monitoring for nitrate, lead, and copper was due in 2005 (Appendix D).

6.4.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15, medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Shungopavi #1 resulted in cumulative score of 32 (high risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density engaged in residential and village administration activities. Within the 50-year groundwater capture zone, most wastewater is collected by a sanitary sewer system and routed to a sewage lagoons west of the water supply well. However, scattered home sites and older areas of the community are without plumbing and thus rely on outdoor privies for sanitation. The probability of contamination from septic waste and common household chemicals is considered medium due to past microbial contamination issues associated with the distribution system.

- Contaminant concerns are associated with household chemical use, the former gasoline station, potential spills along State Highway 264, and maintenance yard activities. Overall risk of contamination from these potential sources is considered moderate.

- Lithologic data indicate that the N-aquifer is protected from surface pollution sources by approximately 600 feet of low permeability Toreva Formation and Mancos Shale, the D-aquifer, and another 60 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of chemical contamination along the well borehole annulus or direct introduction of contaminants to the well from ground surface represents the greatest threat. However, this threat is mitigated by the sanitary seal and approximately 1,300 feet of cement annular seal.

ED_005149_00040842-00057

- Naturally occurring arsenic has been measured at a concentration of 0.017 mg/L at Shungopavi #1. The source of dissolved arsenic is likely overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

A past history of microbial contamination, nearby PSOCs, and arsenic concentrations that exceed the new standard combine to create an overall high susceptibility determination.

6.5 HOPI CULTURAL CENTER

The Hopi Cultural Center PWS (PWSID # 090400260) is a transient non-community public water system that serves the 33-room hotel, a restaurant, the Hopi Arts and Craft Guild, conference room, a former health clinic, and a few nearby homes that haul water. The system consists of a single N-aquifer well, a 40,000-gallon storage tank, and a booster pumping facility that pressurizes the 6-inch schedule 40 PVC distribution system. The Hopi Office of Facilities Management operates the system. The system currently supports the equivalent of about 200 people year round. The PWS is not interconnected with other water systems.

6.5.1 Source Water Supply Wells

Constructed in 1969, Cultural Center #1 is located in a secured area immediately north of the Hopi Cultural Center (Figures 6-5 and 6-7). The well consists of 8-inch steel casing to 1,430 feet followed by 5-inch steel casing containing alternating blank and screen sections from 1,430 to 1,600 feet bgs. The well is equipped with a submersible pump with 45-gpm capacity. At the surface, the well casing extends above the cement pump house floor and has a sanitary seal fabricated from plate steel.

Daily water usage for the period of January 2003 through June 2005 averaged 6,000 gallons per day (gpd) or 6.7 ac-ft/yr. Annual groundwater withdrawals reported by the USGS are provided in Appendix B. Water use has declined slightly with the abandonment of a health clinic and a tribal trailer park that was supported by the PWS. The current water demand is equivalent to pumping approximately 4.2-gpm continuously from the groundwater source (Appendix B).

6.5.2 Administrative Protection and Source Water Delineation

Figure 6-6 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around the two supply wells located on the western side of Second Mesa. The ground surface near Cultural Center #1 slopes north toward the mesa edge. The administrative protection zone does not overlap with that of any other supply wells in the Second Mesa area.

Figure 6-7 shows the aerial base with the modeled groundwater capture zone and potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum capacity is defined as eighteen hours per day of pumping (75-percent run time) at current pump capacity.

ED_005149_00040842-00058

The theoretical maximum pumping rate for Cultural Center #1 (48,600 gpd) is not reached by the year 2055.

The 10- and 50-year time of travel (TOT) particle tracking path lines for Cultural Center #1 are shown on Figure 6-7. The 50-year TOT capture zone width is approximately 990 feet (495-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 36 feet by the year 2055. The predicted drawdown from pre-development conditions is approximately 32 feet by the year 2055 in the overall administrative protection area defined by the supply well shown on Figure 6-6.

6.5.3 Contamination Source Inventory

On June 16, 2005 Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as a medium to high-density (more than 100 people) commercial and residential area. This designation is commonly associated with low to medium susceptibility to sources of contamination. Adjacent lands within the 50-year TOT groundwater capture zone consist of vacant, relatively pristine areas and a portion of the hotel and relatively abandoned trailer park.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zone shown on Figure 6-6. A total of 13 PSOCs were identified within the Cultural Center #1 administrative protection zone, with 5 of these within the 50-year TOT capture zone. Field ranked potential risk factors range from low to high. Of the 5 PSOCs within the 50-year TOT capture zone, four were considered medium to high risk due to (1) proximity and relative elevation in respect to the wellhead; (2) spill potential along the Turquoise Trail (IUR), (3) sanitary sewer lines (MSL), (4) the wastewater package treatment plant (MST), and (5) naturally occurring inorganic (NOI) arsenic concentrations in the source water. The PSOC within the 50-year TOT capture zone considered low risk is the hotel laundry facility (CLD).

A review of existing records maintained by the Hopi Tribe and EPA indicate that no other PSOC have been identified beyond those determined during the field survey.

6.5.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCL values for regulated chemical and radiological contaminants. The Cultural Center PWS has no recorded MCL violations. However, Cultural Center #1 arsenic concentrations exceed the new arsenic standard of 0.010 mg/L that becomes effective January 2006. In 2004, an arsenic concentration of 0.017 mg/L was measured in the source water.

ED_005149_00040842-00059

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. The transient non-community PWS is not required to monitor for many of the contaminant groups required for community public water systems and is not required to prepare annual consumer confidence reports (CCRs). However, in 1998 the source water was sampled and analyzed for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), inorganic compounds (IOCs); and radiological contaminants. The Cultural Center PWS is required to monitor monthly for bacteria, and annually for nitrate and disinfection by-products.

Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. According to the EPA SDWIS, the Hopi Cultural Center PWS has not been collecting the required annual samples for nitrate. Monitoring results for the PWS are provided in Appendix D.

6.5.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15, medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Cultural Center #1 resulted in cumulative score of 20 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a medium to high population density engaged in commercial tourism and residential activities. Within the 50-year groundwater capture zone, wastewater is collected by a sanitary sewer system and routed to a package treatment plant, thenceforth to sewage lagoons located north of the well. Significant wastewater collection and treatment activities upgradient and in close proximity to the well, coupled with a history of non-permitted wastewater discharges to the north of the sewage lagoon system, increases the potential of microbial contamination of the source water.

- Contaminant concerns associated with the use and storage of common household chemicals and the laundry facilities are considered low. Nonetheless, storage of chemical products near the wellhead should be minimized.

- Lithologic data indicate that the N-aquifer is protected from surface pollution sources by approximately 600 feet of low permeability Toreva Formation and Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of chemical contamination along the well borehole annulus or direct introduction of contaminants to the well from ground surface represents the greatest threat to this water supply. However, the sanitary seal and concrete pump house floor minimizes this

ED_005149_00040842-00060

concern. Neither the existence nor extent and quality of a cement annular seal around the well casing are known.

- Naturally occurring arsenic has been measured at a concentration of 0.017 mg/L at Cultural Center #1. The source of dissolved arsenic is likely overlying fine-grained sediments but the exact lithologic horizon has not been definitively determined.

6.6 HOPI VETERANS CENTER

The Hopi Veterans Center PWS (PWSID # 090400316) serves a fitness facility, concessions, offices, and large public events such as concerts and sporting events throughout the year. The system consists of a single N-aquifer well, a 100,000-gallon storage tank, and a gravity-fed distribution system comprised of 6-inch schedule 40 PVC (Cadmus, 2004). The PWS is not interconnected with any other water systems.

Built circa 1980, the system has three service connections that provide water for both permanent residents and a transient population. Approximately 15 families are reported to haul water from a single water distribution point provided at the Veterans Center. An equivalent year-round population of about 100 people is served by the PWS. The system is managed and operated by the Hopi Office of Facilities Management and is funded by the Tribe.

6.6.1 Source Water Supply Wells

Constructed in 1977, the Veterans Memorial Center (VMC) #1 well is located in a secured, fenced area immediately south of the Hopi Veterans Center (Figures 6-5 and 6-8). The well consists of 8-inch steel casing to 1,023 feet with an open-borehole completion from that depth to 1,182 feet bgs. The well is equipped with a submersible pump having a 59-gpm capacity. At the surface, the well casing extends above the pump house cement floor and has a fabricated steel plate that does not form a proper sanitary seal.

Average daily water usage is about 2,400 gallons per day (gpd) or 2.7 ac-ft/yr. Annual groundwater withdrawals reported by the USGS are provided in Appendix B. The current water demand is equivalent to pumping approximately 1.7-gpm continuously from the groundwater source (Appendix B).

6.6.2 Administrative Protection and Source Water Delineation

Figure 6-6 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around the two supply wells located on the western side of Second Mesa. The ground surface near VMC #1 slopes north toward the Veterans Center. The administrative protection zone does not overlap with other supply wells.

Figure 6-8 shows the aerial base with the modeled groundwater capture zone and potential sources of contamination (PSOCs) identified during the field survey. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Second Mesa area.

ED_005149_00040842-00061

Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The theoretical maximum pumping rate for VMC #1 is not reached by the year 2055.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for Veterans Memorial Center #1 are shown on Figure 6-8. The 50-year TOT capture zone width is approximately 560 feet (280-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. The predicted maximum drawdown from pre-development conditions (year 1955) is approximately 26 feet by the year 2055 in the administrative protection area defined by the supply well shown on Figure 6-8.

6.6.3 Contamination Source Inventory

On June 16, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area was designated as low to medium-density (less than 100 people) municipal/residential area. This designation is commonly associated with low susceptibility to sources of contamination. Adjacent lands within the 50-year TOT groundwater capture zone consist of vacant relatively pristine areas immediately south of the Veterans Center.

Table 6-1 summarizes the results of the PSOC inventory conducted within the administrative protection zone shown on Figure 6-6. A total of 10 PSOCs were identified within the VMC #1 administrative protection zone. Field ranked potential risk factors range from low to medium. Medium risk PSOCs are found in the staging/storage areas (CCY/CSY) located along the western fenced boundary of the Veterans Memorial Center. Old paints, tar, oils, and other maintenance supplies are stored in 5- to 55-gallon containers on old wood pallets and the ground surface. These materials should be fully inventoried and hauled offsite for proper disposal. The original septic leachfield failed and has been replaced by a new leachfield, both leachfields are located north and downgradient of the well head. There were no PSOCs identified within the 50-year TOT capture zone shown on Figure 6-6.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

6.6.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 6-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCL values for regulated chemical and radiological contaminants. The Veterans Center PWS does not have recorded MCL violations. Source water arsenic concentrations have not exceeded the new arsenic standard of 0.010 mg/L for five previous sampling events.

Table 6-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. Consumer confidence reports (CCRs) are intended to educate consumers who in turn are more likely to help protect drinking water sources.

According to the EPA SDWIS, the Veterans Center PWS has not complied with recent monitoring requirements for regulated contaminant groups and the 2004 CCR was not prepared. Routine monitoring for all contaminant groups except nitrite was due by December 31, 2005 (Appendix D).

6.6.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 6-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for VMC #1 resulted in cumulative score of 0 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use consists of a low to medium population density engaged in municipal/residential activities. Wastewater sources are non-existent within the 50-year groundwater capture zone therefore the likelihood of potential microbial contamination is very low.

- Contaminant concerns associated with the use and storage of maintenance supplies are considered low due their location at a lower surface elevation and outside of the 50-year groundwater capture zone. The long-term storage of chemicals should be minimized.

- Lithologic data indicate that the N-aquifer is protected from surface pollution sources by approximately 500 feet of low permeability Toreva Formation and Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of chemical contamination along the well borehole annulus or direct introduction of contaminants to the well from ground surface represents the greatest threat. Although, the well location within a secured area upgradient of the identified PSOCs minimizes this concern. The cement annular seal around the well casing has determined to be relatively poor with the exception of an interval from 940 to 958 feet as determined from geophysical logging (DBS&A, 1998). The well casing is intact based on video logging conducted prior to the geophysics.

- Naturally occurring arsenic concentrations are below the new 0.010 mg/L MCL.

ED_005149_00040842-00063

7.0 THIRD MESA SOURCE WATER ASSESSMENTS

This section describes the source water assessments completed for PWSs that serve the Third Mesa area (Table 1-2). For each PWS, the discussion includes information on (1) general system operation, (2) source water delineation, (3) contamination source inventory, and (4) susceptibility analysis. The PWS descriptions draw from the most recent sanitary surveys completed by Cadmus (2003 and 2004).

Information on PWS administration, system components, well construction, and aquifer characteristics are provided in Tables 3-1 through 3-3. Figure 7-1 shows the location of the various PWSs serving the Third Mesa area.

7.1 KYKOTSMOVI

Kykotsmovi PWS (PWSID# 090400105) serves two schools, the Hopi tribal headquarters, approximately 20 businesses, and 200 residences that comprise an estimated population of 1,650 people. Kykotsmovi is located along the eastern base of Third Mesa near the intersection of State Highway 264 and BIA Route 2. Figures 3-1 and 7-1 show the approximate extent of the service area and water distribution piping, respectively.

The system consists of three N-aquifer wells (two active), two storage tanks, and an extensive gravity-fed distribution system. The distribution system is comprised of schedule 40 PVC and asbestos/concrete (AC) pipes that are primarily 4- , 6-, and 8-inch diameter. Under normal operating conditions, water from both tanks is used concurrently to maintain adequate water pressures throughout the distribution system (Cadmus, 2003).

7.1.1 Source Water Supply Wells

Constructed in 1967, Kykotsmovi #1 is an inactive supply well located immediately west of the Kykotsmovi Day School (DS) (Figure 7-1). The well consists of 8-inch steel casing with perforated intervals from 655 to 990 feet bgs. Inactive since 1993, the well is physically disconnected from the distribution system. The village is in the process of improving well and pumping facilities so that this source can be used in the future. A new submersible pump capable of delivering 25-gpm to the PWS and a new sanitary seal was installed in 2000. The 3-inch pump discharge piping is currently disconnected from the distribution piping, and provides an open conduit for contaminant introduction to the well. The pump discharge piping should be capped until the well can be put back in service.

Kykotsmovi #2, constructed in 1979, is an active supply well located on a hill immediately west of the tribal government buildings. The well consists of 8-inch steel casing that extends to 925 feet bgs, which is followed by 6-inch perforated steel casing from 925 to 1,155 feet bgs. The water operator believes that the original submersible pump is still providing service at a discharge rate of 75-gpm. The well casing extends above the pump house floor, and is capped with a fabricated steel plate sanitary seal.

ED_005149_00040842-00064

Meter readings indicate that daily water usage from Kykotsmovi #2 averaged about 16,100 gallons per day (gpd) for the period of January 2004 through July 2005. This is equivalent to pumping approximately 11-gpm continuously from the groundwater source (Appendix B).

Kykotsmovi Day School #3 is an active supply well located on the Kykotsmovi DS site. The well consists of 8-inch steel casing that extends to 850 feet bgs, which is followed by 6-inch perforated steel casing from 825 to 1,220 feet bgs. The submersible pump currently operates at about 120-gpm. The well casing extends above ground surface, and is completed with a pitless adaptor unit that has a vented sanitary seal. Meter readings indicate that daily water usage from Kykotsmovi DS #3 averaged about 38,000 gallons per day (gpd) for the period of January 2004 through July 2005. This is equivalent to pumping approximately 26-gpm continuously from the groundwater source (Appendix B).

Annual groundwater withdrawals as reported by the USGS indicate that water usage has been relatively stable for the last 15 years. Current usage of about 62 ac-ft/year was apportioned evenly between the two active wells for groundwater capture zone modeling.

7.1.2 Administrative Protection and Source Water Delineation

Figure 7-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located on the eastern side of Third Mesa. Surface topography indicates that surface water drainage is to the southeast toward Oraibi Wash. The individual administrative protection zones overlap due to the proximity of the wells. The administrative protection zone extends from the Village of Oraibi to Oraibi Wash, and covers the entire Village of Kykotsmovi (Figure 7-2).

Figure 7-3 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for Kykotsmovi. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Third Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates for Kykotsmovi #2 and Kykotsmovi DS #3 were assumed to increase 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The maximum pumping capacity for the active wells was not reached by 2055. Tetra Tech has assumed that inactive supply well Kykotsmovi #1will serve in reserve role, and that modeled groundwater capture for closely spaced Kykotsmovi #1 and Kykotsmovi DS #3 is fully represented by the Kykotsmovi DS #3 pumping schedule.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for the two active wells are shown on Figure 7-3. The 50-year TOT capture zones form two separate areas. The capture zone width for Kykotsmovi #2 is approximately 1,580 feet (790-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. The capture zone width for Kykotsmovi DS#3 is larger at approximately 2,320 feet (1,160-foot radius from the pumping well) because of the greater pumping rate.

ED_005149_00040842-00065

In the immediate vicinity of the wells, the predicted maximum drawdown from pre-development conditions (year 1955) for Kykotsmovi #2 and Kykotsmovi DS #3 is approximately 46 and 85 feet respectively by the year 2055. The predicted drawdown from pre-development conditions is approximately 23 feet by the year 2055 in the administrative protection area defined by the two active supply wells shown on Figure 7-2.

7.1.3 Contamination Source Inventory

On July 5, 2005, Tetra Tech completed the field survey with the assistance of the water operator. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes high-density residential areas, with significant commercial and municipal government activities. This designation is commonly associated with medium susceptibility to sources of contamination. The adjacent lands located within the 50-year TOT groundwater capture zone defined for Kykotsmovi #2 are rural and pristine; while the 50-year TOT groundwater capture zone for Kykotsmovi DS #3 consists of mix residential, commercial, and municipal government activities.

Table 7-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 7-2. Within the administrative protection zones there were 8 PSOCs identified for Kykotsmovi #2 and 21 PSOCs identified for Kykotsmovi DS #3. Field ranked potential risk factors range from low to medium. None of the Kykotsmovi #2 PSOCs were identified within the 50-year TOT capture zone, while 7 of the Kykotsmovi DS #3 PSOCs were within the 50-year TOT. Three of these are considered medium risk; including (1) a fuel oil aboveground storage tank that formerly serviced the day school (CFA), (2) day school operations (MSC-1), and (3) the day school maintenance garage (MMP).

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

7.1.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 7-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCLs for regulated chemical and radiological contaminants. The Kykotsmovi PWS has exceeded the primary MCL for total coliform, an indicator of potential microbial contamination, once in the distribution system since 1995. Lead concentrations within Mission School piping exceeded the MCL once in 1993.

Table 7-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Kykotsmovi

ED_005149_00040842-00066

PWS has not achieved compliance with miscellaneous SVOC and VOC monitoring requirements and has failed to routinely prepare CCRs.

The CCR for 2004 is provided in Appendix D with the water quality data. Routine monitoring for nitrate, IOCs, SOCs, and VOCs are due by December 31, 2005.

7.1.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 7-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Kykotsmovi #2 resulted in cumulative score of 0 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of low to high population density areas. Within the 50-year TOT groundwater capture zone defined the adjacent land use is rural and pristine. Wastewater systems serving Kykotsmovi are all located at a lower elevation than the well head. Individual outhouses or privies are located approximately 2,000 feet to the west on the mesa top. The probability of contamination from septic waste and household or commercial chemicals is considered low due to the remote well location.

- Chemical contaminant concerns are also considered low because the well is located upgradient from identified PSOCs. Further, there were no PSOCs identified within the 50-year TOT groundwater capture zone.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 400 feet of low permeability Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. There is positive drainage away from well, the area is secure, and there is a reported cement annular seal extending to 925 feet bgs; however, the overall integrity of the cement seal is unknown.

- Naturally occurring inorganic contaminants are not a concern.

The susceptibility analysis for Kykotsmovi DS #3 resulted in cumulative score of 27 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

ED_005149_00040842-00067

- Adjacent land use within the administrative protection and 50-year TOT groundwater capture zone consists of medium to high population density areas. A sanitary sewer system serves the area. The probability of microbial contamination is considered low.

- Chemical contaminant concerns are considered moderate due to the location of multiple PSOCs, including fuel sources, within both the administrative protection and 50-year TOT groundwater capture zones.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 400 feet of low permeability Mancos Shale, the D-aquifer, and another 80 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents a significant threat as water tends to pond around Kykotsmovi DS #3 during storms. Inactive supply well Kykotsmovi #1 probably represents the greatest threat to source water quality at least until the well head is properly sealed to prevent introduction of contaminants directly to the aquifer. An abandoned well at the Mission School located north of State Highway 264 also poses a threat.

- Naturally occurring inorganic contaminants are not a concern.

7.2 BACAVI

Bacavi PWS (PWSID# 090400687) serves a residential population of approximately 450 people within the village located on top of Third Mesa. Figures 3-1 and 7-1 show the approximate extent of the service area and water distribution piping, respectively.

The system consists of one N-aquifer well, one storage tank, and a gravity-fed distribution system. The distribution system is comprised of schedule 40 PVC and asbestos/concrete (AC) pipes primarily 6-inch in diameter that provides service to 134 potential connections (Cadmus, 2003). The Bacavi PWS distribution system is interconnected with the Hotevilla Village system (PWSID #090400700) for emergency water service.

7.2.1 Source Water Supply Wells

Bacavi #1 is located in a locked fenced area on the west side of State Highway 264 (Figure 7-1). The well, constructed in 1999, consists of 8-inch steel casing to a depth of 1,415 feet bgs followed by an open borehole to a total depth of 1,780 feet bgs. The submersible pump is capable of delivering 40-gpm to the PWS. The surface completion consists of a pitless adaptor unit and vented sanitary well seal. Groundwater is pumped to an adjacent pump house containing electric controls and disinfection equipment. Prior to 1992, water was provided to the community on a limited by the BIA operated Hotevilla Day School in exchange for sewer service.

Meter readings indicate daily water usage from Bacavi #1 averaged about 19,000 gallons per day (gpd) for the period of January 2003 through December 2004.

This is equivalent to pumping approximately 13.2-gpm continuously from the groundwater source (Appendix B). Annual groundwater withdrawals as reported by the USGS indicate that water usage has been relatively stable for the last 10 years at about 21.3 ac-ft/year.

7.2.2 Administrative Protection and Source Water Delineation

Figure 7-4 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around each supply well located in the Bacavi/Hotevilla area of Third Mesa. The surface topography indicates that surface water drainage is to the northeast toward State Highway 264. The administrative protection zones for supply wells serving the Bacavi, Hotevilla, and Hotevilla Day School public water systems overlap substantially due to the proximity of the wells. Bacavi #1 is within 1,800 feet of three other supply wells (Hotevilla #1, Hotevilla Day School #1, and Hotevilla Day School #2)

Figure 7-5 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for Bacavi #1. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Third Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates for Bacavi #1 were assumed to escalate 2 percent per year until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The maximum pumping capacity was not reached in the year 2046.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for the Bacavi #1 is shown on Figure 7-5. The capture zone width is approximately 1,580 feet (790-foot radius from the pumping well) perpendicular to the ambient direction of groundwater flow. In the immediate vicinity of the well, the predicted maximum drawdown from pre-development conditions (year 1955) is approximately 53 feet by the year 2055. The predicted drawdown from pre-development conditions is approximately 23 feet by the year 2055 in the administrative protection area defined by the active supply wells shown on Figure 7-5.

7.2.3 Contamination Source Inventory

On July 6, 2005, Tetra Tech completed the field survey with the assistance of the water operator. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes small but high-density residential areas within the older areas of Hotevilla and Bacavi, several commercial enterprises, and municipal government/school activities. These types of activities are commonly associated with medium susceptibility to sources of contamination. The adjacent lands within the 50-year TOT groundwater capture zone consist of low density housing, limited commercial and dryland agricultural activity in an otherwise pristine environment.

Table 7-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 7-4. Within the Bacavi #1 administrative protection zone there were 25 PSOCs identified. Field ranked potential risk factors range from low to high.

Within the 50-year TOT capture zone for Bacavi #1 there were seven of these PSOCs, six of which are considered medium risk. The medium risk PSOCs include (1) a horse corral located north of the well (AOA), (2) a tire and auto repair shop (CAR), (3) a former hydraulic fluid storage area northeast of the well (CFA), (4) an abandoned fuel station (CHG-1), (5) the current Hotevilla gas station (CSS), and (6) the potential for chemical spill along State Highway 264 (IUR).

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

7.2.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 7-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCLs for regulated chemical and radiological contaminants. The Bacavi PWS has exceeded the primary MCL for total coliform, an indicator of potential microbial contamination, one time in the distribution system since 1996. Antimony and beryllium concentrations exceeded their respective MCLs during one sampling event in 1993 at an unknown location within the distribution system.

Table 7-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Bacavi PWS has achieved compliance with monitoring requirements and appears to be on track with preparation of the annual CCR.

Routine monitoring for asbestos and nitrate were due by December 31, 2005.

7.2.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 7-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Bacavi #1 resulted in cumulative score of 23 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of low to high population density areas. Within the 50-year TOT groundwater capture zone, the adjacent land use is scattered residential with limited commercial activity. Wastewater systems serving Bacavi and the Hotevilla Day School are all located cross-gradient or at a lower elevation than the well head. Individual septic systems serve scattered home sites but the density is sufficiently low to reduce this contaminant concern to a low risk.

- Chemical contaminant concerns are also considered moderate due to the proximity of the well site to several potential contaminant sources.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 750 feet of low permeability Mesaverde Group sediments and the Mancos Shale, the D-aquifer, and another 70 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus represents the greatest threat. There is positive drainage away from well, the area is secure, and there is a reported cement annular seal extending to 1,415 feet bgs; however, the overall integrity of the cement seal is unknown.

- Naturally occurring inorganic contaminants are not a concern within the source water.

7.3 HOTEVILLA

Hotevilla PWS (PWSID# 090400700) serves a residential population of approximately 1,200 people, a post office, the Village community building, and a gasoline service station on Third Mesa. In addition to over 140 individual service connections, there are five public hydrants used by residents who do not have indoor plumbing.

The system consists of two N-aquifer wells, a storage tank, and a gravity-fed distribution system comprised primarily of 4- and 6-inch PVC pipe. The second well is newly constructed and is expected to begin providing water in 2006. Figures 3-1 and 7-1 show the approximate extent of the service area and water distribution piping, respectively.

7.3.1 Source Water Supply Wells

Hotevilla #1 supply well is located within a locked fenced area immediately north of the BIA operated Hotevilla Day School. Installed in 1994, the well consists of 8-inch steel casing that extends to 1,420 feet bgs and an open-borehole completion to a total depth of 1,819 feet bgs. Aesthetic water quality issues and a history of sand pumping has required the replacement of several submersible pumps and associated equipment. The current submersible pump produces 47-gpm from a pump setting of 1,050 feet bgs. The surface completion consists of a pitless adaptor unit and a vented sanitary seal.

ED_005149_00040842-00071

Hotevilla #2 supply well is located within a locked fenced area south of the village (Figure 7-1). Installed in 2004, the well consists of 12-inch steel casing that extends to 1,460 feet bgs with 6-inch perforated casing extending from 1,460 to 1,860 feet bgs. A submersible pump of unknown capacity has been installed and is scheduled to provide water to the PWS in 2006. The surface completion consists of a pitless adaptor unit with a high-quality vented sanitary seal.

Meter readings indicate that daily water usage from Hotevilla #1 averaged about 17,200 gallons per day (gpd) for the period of January 2005 through August 2005. This is equivalent to pumping approximately 11.9-gpm continuously or 19.2 ac-ft/year from the groundwater source (Appendix B). Annual groundwater withdrawals reported by the USGS have varied significantly over the last 20-years. However, the long-term average of 18.2 ac-ft/year is in close agreement with recent usage data from Hotevilla #1. The new Hotevilla #2 supply well is expected to begin providing water to the Hotevilla PWS in 2006.

7.3.2 Administrative Protection and Source Water Delineation

Figure 7-4 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around the wells located in the Bacavi/Hotevilla area of Third Mesa. The topography indicates that surface water drains north toward the mesa edge. Administrative protection zones for the supply wells serving the Bacavi, Hotevilla, and Hotevilla Day School public water systems overlap substantially due to their close proximity. Hotevilla #1 is within 400 feet of Hotevilla Day School #1 and #2, and within 1,800 feet of Bacavi #1. The closest supply well to Hotevilla #2 is Bacavi #1, which is located approximately 4,400 feet to the northeast.

Figure 7-5 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for the Hotevilla PWS. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Third Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates for Hotevilla #1 and #2 were assumed to increase 2 percent per year from current conditions until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The Hotevilla #2 pumping schedule begins at a rate that is roughly 30 percent of current Hotevilla #1 withdrawals. The theoretical maximum was not reach for either well by the year 2055.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for the Hotevilla #1 and #2 are shown on Figure 7-5. The capture zone width for Hotevilla #1 is approximately 1,560 feet (780-foot radius from the pumping well) in combination with the pumping from Hotevilla Day School #1. The predicted capture zone width for Hotevilla #2 is approximately 1,550 feet. The predicted drawdown from pre-development conditions is approximately 23 feet by the year 2055 in the administrative protection area defined by the active supply wells shown on Figure 7-5. Drawdown near the pumping wells is predicted to reach about 50 feet by the year 2055.

ED_005149_00040842-00072

7.3.3 Contamination Source Inventory

On August 25, 2005, Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes high-density residential areas within the older areas of Hotevilla and Bacavi, several commercial enterprises, and municipal government/school activities. These types of activities are commonly associated with medium susceptibility to sources of contamination. The adjacent lands within the 50-year TOT groundwater capture zone for Hotevilla #1 consist of medium density housing, limited commercial and dryland agricultural activity, and municipal school and government activities. The adjacent lands within the 50-year TOT groundwater capture zone for Hotevilla #2 include scattered home sites and limited dryland agricultural activity within an otherwise pristine environment.

Table 7-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 7-4. Within the Hotevilla #1 administrative protection zone there were 25 PSOCs identified with field ranked potential risk factors ranging from low to high. The 50-year TOT capture zone included seven of these PSOCs, with four being medium to high risk. The medium risk PSOCs include (1) the potential for chemical along State Highway 264 (IUR), (2) daily use of potential chemical contaminants at the Hotevilla Day School (MSC), and (3) the collection and routing of wastewater to the Hotevilla sewage lagoon (MSL). The inactive supply well Hotevilla Day School #2 provides a direct conduit to the source water from surface contamination as it is improperly abandoned (CAW-1) and therefore represents a high risk.

The Hotevilla #2 administrative protection zone contains the same 25 PSOCs as identified for Hotevilla #1. However, within the 50-year TOT capture zone, only residential septic tanks were identified as potential PSOCs.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

7.3.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 7-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCLs for regulated chemical and radiological contaminants. The Hotevilla PWS has not exceeded primary MCLs during routine monitoring for contaminants, with the exception of a single detection of total coliform near a "dead end", or stagnant zone, in the distribution system in 2003.

Table 7-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants.

ED_005149_00040842-00073

Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the Hotevilla PWS did not meet regular monitoring requirements in 2004 for several contaminant groups and has been inconsistent with CCR preparation. Other EPA monitoring information suggests that the routine monitoring was completed in December 2004, and the CCR are now being prepared on a regular basis. Routine nitrate sampling is due by December 31, 2005.

7.3.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 7-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Hotevilla #1 resulted in cumulative score of 23 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of low to high population density areas. Within the 50-year TOT groundwater capture zone land use consists of residential, limited commercial, and municipal associated with the BIA school and community administration. Wastewater systems serving the Hotevilla Day School are located up gradient of the well head thus presenting a contaminant risk. Individual septic systems serve scattered home sites but the density is sufficiently low to reduce this contaminant concern to a low risk.

- Chemical contaminant concerns are also considered moderate due to the proximity of the well site to several potential contaminant sources.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 750 feet of low permeability Mesaverde Group sediments and the Mancos Shale, the D-aquifer, and another 70 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus, or through improperly abandoned Hotevilla Day School #2 represents the greatest threats. There is positive drainage away from well, the area is secure, and there is a reported cement annular seal extending to 1,420 feet bgs; however, the overall integrity of the cement seal is unknown. Abandonment of the BIA well is a high priority for source water protection of all Hotevilla area PWSs.

- Naturally occurring inorganic contaminants are not a concern within the source water.

ED_005149_00040842-00074

The susceptibility analysis for Hotevilla #2 resulted in cumulative score of 3 (low risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of low to high population density areas. Within the 50-year TOT groundwater capture zone land use consists of scattered home sites only. Individual septic systems serve the homes; however, the density is sufficiently low to reduce this contaminant concern to a low risk ranking.

- Chemical contaminant concerns are also considered low due to the location of well site relative to potential contaminant sources.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 750 feet of low permeability Mesaverde Group sediments and the Mancos Shale, the D-aquifer, and another 70 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migration of contamination along the well borehole annulus, represent the greatest threats. There is positive drainage away from well, the area is secure, and there is a cement annular seal extending to 1,460 feet bgs. The well cementing process followed acceptable placement techniques as described in the Hopi Water Code and was overseen by Hopi WRP technicians. The vented sanitary seal is less than 18" above grade.

- Naturally occurring inorganic contaminants are not a concern within the source water.

7.4 HOTEVILLA DAY SCHOOL

BIA Hotevilla PWS (PWSID# 090400052) provides service to the Hotevilla Day School, Head Start program, and residences located on the BIA school site. The water needs of roughly 260 people are met during normal school operations through 18 service connections (Cadmus, 2003). The PWS is interconnected with the Hotevilla PWS (PWSID #090400700) and the Bacavi PWS (PWSID #090400687) for emergency service situations only, and has provided limited water service to Hotevilla and Bacavi prior to construction of separate water systems that now support those villages.

The system consists of two N-aquifer wells (one active), a storage tank, and a gravity-fed distribution system comprised of 4- and 6-inch PVC, 2-inch galvanized iron, and significant asbestos concrete pipe. Figures 3-1 and 7-1 show the approximate extent of the service area and water distribution piping on Third Mesa, respectively.

7.4.1 Source Water Supply Wells

Hotevilla Day School #1 is located on the northern side of the Hotevilla Day School (DS) compound in a small locked pump house. Constructed in 1957, Hotevilla DS #1 is one of the oldest N-aquifer wells on

ED_005149_00040842-00075

the Hopi Reservation. Information on well constructed and condition is sparse. Cadmus (2003) reported that the well was drilled to 1,500 feet bgs with the most recent submersible pump set at 1,071 feet bgs in 1985. A depth of 1,757 feet bgs has also been reported.

A 6-inch steel well casing extends one inch above the concrete pump house floor, and does not have a properly ventilated sanitary seal. The nature of well completion and zone of perforation (or open-hole interval) is unknown. The pump house floor does not contain a drain that could reduce ponding around the well casing.

Hotevilla Day School # 2 is an inactive well located about 150 feet northwest of Hotevilla DS #1 (Figure 7-4). Installed in 1970, the well consists of 8-inch steel casing that extends to 1,450 feet bgs and 6-inch perforated casing from 1,450 to 1,800 feet bgs. The well was removed from service in 1992 after an electrical fire eliminated any future use of the well (Cadmus, 2003). Although the well has been physically disconnected from the BIA Hotevilla system, it has not been properly abandoned and presents an ongoing high risk for surface induced contamination to the N-aquifer, and therefore all Hotevilla area PWSs.

Meter readings indicate that daily water usage from Hotevilla DS #1 averaged about 3,600 gallons per day (gpd) for the period of May 2004 through July 2005. This is equivalent to pumping approximately 2.5-gpm continuously or 4.0 ac-ft/year from the groundwater source (Appendix B). Annual groundwater withdrawals reported by the USGS do not distinguish between use at the Hotevilla Day School and the village making evaluation of long-term water use trends difficult.

7.4.2 Administrative Protection and Source Water Delineation

Figure 7-4 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around the supply wells located in the Bacavi/Hotevilla area of Third Mesa. The topography indicates that surface water drains north toward the mesa edge. Administrative protection zones for supply wells serving the Bacavi, Hotevilla, and Hotevilla Day School public water systems overlap substantially due to their close proximity. Hotevilla DS #1 is within 400 feet of two supply wells (Hotevilla Day School #2 and Hotevilla #1), and 1,500 feet from another (Bacavi #1).

Figure 7-5 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for the BIA Hotevilla PWS. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Third Mesa area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). Well pumping rates for Hotevilla DS #1 and nearby active supply wells were assumed to escalate 2 percent per year from current conditions until the theoretical maximum capacity is reached. The theoretical maximum is defined by eighteen hours per day of pumping (75-percent run time) with current equipment. The theoretical maximum was not reach by the year 2055.

ED_005149_00040842-00076

The 10- and 50-year time of travel (TOT) particle tracking pathlines for the Third Mesa wells are shown on Figure 7-5. The capture zone width for Hotevilla DS #1 is approximately 1,560 feet (780-foot radius from the pumping well) in combination with the nearby pumping from Hotevilla #1. The predicted drawdown from pre-development conditions is approximately 23 feet by the year 2055 in the administrative protection area defined by the active supply wells shown on Figure 7-5. Drawdown near the pumping wells is predicted to reach about 50 feet by the year 2055.

7.4.3 Contamination Source Inventory

On July 8, 2005, Tetra Tech completed the field survey with the assistance of the water operator. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes high-density residential areas within the older areas of Hotevilla and Bacavi, several commercial enterprises, and municipal government/school activities. These types of activities are commonly associated with medium susceptibility to sources of contamination. The adjacent lands within the 50-year TOT groundwater capture zone for Hotevilla DS #1 consist of medium density housing, limited commercial and dryland agricultural activity, and municipal school and government activities.

Table 7-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 7-4. Within the Hotevilla DS#1 administrative protection zone, there were 24 PSOCs identified, with field ranked potential risk factors ranging from low to high. The 50-year TOT capture zone included six of these PSOCs, with three being medium to high risk. The medium risk PSOCs include (1) the use of potential chemical contaminants at the Hotevilla Day School (MSC), and (2) the collection and routing of wastewater to the sewage lagoon systems (MSL). The inactive supply well Hotevilla Day School #2 provides a direct conduit to the source water for surface contamination as it is improperly abandoned (CAW-1); therefore it represents a high risk for aquifer contamination.

A review of existing records maintained by the Hopi Tribe and EPA indicated that other PSOC have not been identified beyond those determined during the field survey.

7.4.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 7-2 provides a summary of positive test results for the presence of bacteriological contamination and any exceedance of established MCLs for regulated chemical and radiological contaminants. The BIA Hotevilla PWS has not exceeded primary MCLs during routine monitoring for contaminants with the exception of two positive detections of total coliform within the distribution system in 2001 and 2002.

Table 7-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years

ED_005149_00040842-00077

for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, the BIA Hotevilla PWS did not meet regular monitoring requirements in 2004 for several contaminant groups and has been inconsistent with CCR preparation. Regular monitoring for VOCs, SOCs, and IOCs was due by December 31, 2005.

7.4.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 7-4 provides a score and cumulative risk ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for Hotevilla DS#1 and DS#2 resulted in cumulative score of 26 (medium risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of low to high population density areas. Within the 50-year TOT groundwater capture zone, land use consists of residential and municipal activities associated with the BIA school. Wastewater systems serving the Hotevilla Day School are located up-gradient and close proximity to the wells, thus presenting a contaminant risk. Individual septic systems serve scattered home sites; however, the density is sufficiently low to reduce this contaminant concern to a low risk ranking.

- Chemical contaminant concerns are also considered moderate due to the proximity of the well site to potential contaminant sources at the school.

- Lithologic data indicate the source water is protected from surface pollution sources by approximately 750 feet of low permeability Mesaverde Group sediments and the Mancos Shale, the D-aquifer, and another 70 feet of low permeability Carmel Formation which confines the underlying N-aquifer. This stratigraphic section will significantly impede downward contaminant migration.

- Possible downward migrations of contamination along the well borehole annulus, or through improperly abandoned Hotevilla DS #2 represent the greatest threats. The active well, Hotevilla DS#1, is vulnerable to surface contamination because the surface casing is completed near floor level and has an inadequate sanitary seal. The lack of well completion details and information on well integrity increase the vulnerability of Hotevilla DS #1 to contamination.

- Surface completion upgrades for active supply well Hotevilla DS #1, and the proper abandonment of inactive supply well Hotevilla DS #2 are considered a high priority.

- Naturally occurring inorganic contaminants are not a concern within the source water.

ED_005149_00040842-00078

8.0 MOENKOPI SOURCE WATER ASSESSMENTS

This section describes the source water assessments completed for PWSs that serve the Moenkopi area located adjacent to the Navajo community of Tuba City, Arizona (Figure 1-1 and Table 1-1). For each PWS, the discussion includes information on (1) general system operation, (2) source water delineation, (3) contamination source inventory, and (4) susceptibility analysis. The PWS descriptions draw from the most recent sanitary surveys completed by Cadmus (2003 and 2004).

Information on PWS administration, system components, well construction, and aquifer characteristics is provided in Tables 3-1 through 3-3. Figure 8-1 shows the location of the two PWSs serving the Moenkopi area.

8.1 UPPER VILLAGE OF MOENKOPI

Upper Moenkopi PWS (PWSID# 090400104) serves a residential population of approximately 1,000 people through 250 service connections (Cadmus, 2004). The system is comprised of three N-aquifer supply wells, two storage tanks, and a distribution system. Water from the three wells is combined at a common header and pumped to the distribution system. The storage tanks are 100,000 and 390,000 gallons in size and provide operating pressure to the distribution system. A new C-aquifer water source has been developed but will not been incorporated into the PWS until natural water quality issues can be addressed through treatment.

Figures 8-1 shows the water distribution piping layout for the Upper Moenkopi and Lower Moencopi PWSs.

8.1.1 Source Water Supply Wells

Moenkopi #1 is located on the south side of U.S. Highway 160 within a locked pump house enclosed by a chain link fence. Constructed in 1977, Moenkopi #1 consists of 8-inch steel casing from the surface to 140 feet deep, with perforations from 60-129 feet below surface. . The well casing extends 32-inches above the concrete pump house floor, and is sealed with a vented fabricated steel plate cover. A submersible pump with 41-gpm capacity is currently in the well.

Moenkopi #2 is located approximately 350 feet west of the pump house in an open area without access controls. Constructed in 1982, this well consists of 8-inch steel casing to 135 feet bgs, with two perforated sections between 75 and 135 feet bgs. The well extends above ground surface and is completed with a pitless adaptor unit. It is equipped with a submersible pump with a reported capacity of 43 gpm. This well operates on a timer cycling on and off every two hours.

Moenkopi #3 is located approximately 150 feet east of the pump house in an open area without access controls. Constructed in 1991, the well consists of 8-inch steel blank and perforated casing of unknown depth. It is equipped with a submersible pump of unknown capacity. The well extends above ground surface and is completed with a pitless adaptor unit and a sanitary seal that is not vented. This well is operated continuously until the pumping level drops below the low-level shutoff probe for the pump (Cadmus, 2004).

ED_005149_00040842-00079

Meter readings indicate that daily water usage from the Upper Moenkopi well field averaged about 79,700 gallons per day (gpd) for the period of January 2004 through June 2005. This is equivalent to pumping approximately 55-gpm continuously or 89 ac-ft/year from the groundwater source (Appendix B). Annual groundwater withdrawals reported by the USGS show a steady increase in water use over the last 15 years.

8.1.2 Administrative Protection and Source Water Delineation

Figure 8-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zones around the Upper Moenkopi supply wells located adjacent to U.S. Highway 160. The topography indicates that surface water drainage is to the southeast toward the Pasture Canyon Wash. Essentially one administrative protection zone is formed by the Upper Moenkopi well field due to the proximity of the wells to one another.

Figure 8-3 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for the Upper Moenkopi PWS. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Moenkopi area. Aquifer properties and pumping schedules for the modeling effort are provided in Appendix B, and are based on information compiled during the PWS inventory (Section 3). For the modeling, the combined Upper Moenkopi well field pumping was apportioned evenly between the three wells, and escalated 2 percent per year from current conditions until the estimated maximum capacity is reached.

The 10- and 50-year time of travel (TOT) particle tracking pathlines for the Upper Moenkopi wells are shown on Figure 8-3. The capture zone width for the well field is approximately 3,500 feet (1,750-foot radius from the pumping center). The predicted drawdown from pre-development conditions is approximately 49 feet by the year 2055 near the pumping center.

8.1.3 Contamination Source Inventory

The contaminate source inventory was completed over three days in July and August 2005. Tetra Tech completed the field survey with the assistance of the water operator and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes high-density residential areas, irrigated agriculture, a commercial strip along U.S. Highway 160, and municipal government/school activities. These types of activities are commonly associated with medium to high susceptibility to sources of contamination. The lands within the 50-year TOT groundwater capture zone defined by the Upper Moenkopi well field are of similar use to those described above.

Table 8-1 summarizes the results of the PSOC inventory conducted within the administrative protection zones shown on Figure 8-2. Within the Upper Moenkopi well field administrative protection zone there were 29 PSOCs identified with field ranked potential risk factors ranging from low to high. The 50-year TOT capture zone included eight of these PSOCs, with six being medium to high risk.

ED_005149_00040842-00080

The medium risk PSOCs include (1) Upper Moenkopi high density housing near the wells (MHD-1), (2) high density Navajo housing upgradient of the wells (MHD-2), (3) past illegal dumping practices within Pasture Canyon Wash (MPR-2), and (4) Navajo government offices and school in Tuba City (MSC-1). The high risk PSOCs includes (1) Cal's Auto Body Repair (CAR/CBS) and (2) chemical spill potential along the U.S. Highway 160 transportation corridor.

Figure 8-3 also shows the delineated extent of two petroleum hydrocarbon contaminant plumes from leaking underground storage tank sites, and an inorganic contaminant plume originating form the former Tuba City Landfill. These sites border the 50-year TOT groundwater capture zone of the Upper Moenkopi well field and are the subject of ongoing characterization and remediation efforts. DBS&A (2000a) identified additional PSOCs outside of the administrative protection zones defined for the most recent source water assessment activities.

8.1.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 8-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCLs for regulated chemical and radiological contaminants. The Upper Moenkopi PWS has exceeded the primary MCL for total coliform five times within the distribution system since 1996. Copper and lead have each been detected once in the distribution system above their respective primary MCLs, and nitrite was detected at its primary MCL in the source water represented by Moenkopi #3 during a re-sampling event in 1998.

Table 8-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, Upper Moenkopi has missed some of the sampling dates for regular monitoring requirements but it appears that samples were subsequently collected to achieve compliance.

8.1.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 8-4 provides a score and cumulative risk ranking for the identified PSOCs.
The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination.

ED_005149_00040842-00081

Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 15; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for the Upper Moenkopi well field resulted in cumulative score of 50 (high risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of high population density areas. Within the 50-year TOT groundwater capture zone, land use consists of high density residential, commercial, and municipal government activities. Wastewater systems serving the area are located in close proximity to the wells thus presenting a contaminant risk. Individual septic systems serve scattered home sites; however; home site density is sufficiently low to render this contaminant concern a low risk.

- Chemical contaminant concerns are also considered moderate to high due to the proximity of the wells to significant commercial activity along the U.S Highway 160 transportation corridor. Accidental chemical spills along the highway represent the greatest chemical contamination threat.

- Lithologic data indicate the source water is vulnerable to surface pollution sources because there is less than 50 feet of vertical separation between the ground surface and underlying unconfined, sandstone aquifer (N-aquifer). Upper Moenkopi is located near the boundary of the N-aquifer as discussed in Section 4. Here, the N-aquifer is unconfined, and lacks the thick sequence of confining beds above it, as is typical of other N-aquifer PWS discussed previously. At Upper Moenkopi, the material overlying the aquifer consists of porous sands and sandstones that provide a limited natural barrier to downward contaminant migration. As a result, the stratigraphic and hydrologic protections afforded elsewhere as regards the other N-aquifer PWS are lacking.

- Possible downward migration of contamination along the well borehole annulus also represents a significant threat. Well completion information for Moenkopi #1 and #2 show cement annular seals to 20 feet bgs; no information for Moenkopi #3 is available. The limited interval seal of unknown integrity increases the overall risk of contamination.

- Naturally occurring inorganic contaminants are not a concern within the N-aquifer source water.

8.2 LOWER VILLAGE OF MOENCOPI

Lower Moencopi (PWSID #090400393) serves a residential population of approximately 200 people through five water distribution points. The system consists of a single spring water source, an 18,000-gallon storage tank, and a gravity-fed looped distribution system consisting of 6-inch PVC mains. An EPA-funded water system improvement project includes plans for connecting the distribution system to the Upper Village of Moenkopi.

Figure 8-1 shows the water distribution piping layout for the Upper Moenkopi and Lower Moenkopi PWSs.

ED_005149_00040842-00082

8.2.1 Source Water Supply Wells

The source water spring is located along a dirt road immediately upgradient of the Lower Village (Figure 8-1). Source water is collected in a vault located directly below the spring house structure. Spring overflow is routed to a ditch located about 150 feet east of the spring building, and provides water for nearby irrigate fields. The estimated source water spring firm-yield discharge is 25-gpm from the N-aquifer.

Water usage records are not maintained for the Lower Village. Estimated water use is low because it must be hauled for residential use. A current daily water use rate of 20 gallons per day per capita (gpcd) equates to 4,000 gallons per day for the water system.

8.2.2 Administrative Protection and Source Water Delineation

Figure 8-2 shows the local topography with the Hopi Water Code prescribed 1-mile radius administrative protection zone around the Lower Moencopi source water spring. The topography indicates that surface water drainage is to the southeast toward Pasture Canyon Wash. Moenkopi Wash is a natural hydrologic boundary that truncates the administrative protection zone to the south.

Figure 8-3 shows the aerial base with modeled groundwater capture zones and potential sources of contamination (PSOCs) identified during the field survey for the Lower Moencopi and Upper Moenkopi PWSs. Source water delineation was facilitated through the construction and use of a numerical groundwater model for the Moenkopi area. The source water spring captures natural groundwater discharge along the contact between the Navajo Sandstone and underlying Kayenta Formation. The groundwater discharge rate is likely greater than other springs in the area at a similar elevation because of bedrock fractures.

There is considerable degree of uncertainty in the orientation of the groundwater capture by the spring. This uncertainty is incorporated in the time of travel (TOT) estimates depicted on Figure 8-3. The 50-year TOT extends approximately 1,500 feet upgradient of the source water spring.

8.2.3 Contamination Source Inventory

The contaminate source inventory was completed on August 25 and 26, 2005. Tetra Tech completed the field survey with the assistance of the water operator, CSA, and a Hopi WRP technician. The surrounding land use within the administrative protection zone was evaluated for PSOCs. The administrative protection area includes high-density residential areas, irrigated agriculture, a commercial strip along U.S. Highway 160, and municipal government/school activities. These types of activities are commonly associated with medium to high susceptibility to sources of contamination. The adjacent lands within the 50-year TOT groundwater capture zone, as defined by the source water spring, consist primarily of residential and irrigated agricultural activities.

ED_005149_00040842-00083

Table 8-1 summarizes the results of the PSOC inventory conducted within the Lower Village administrative protection zone shown on Figure 8-2. Within the administrative protection zone there were 28 PSOCs identified with field ranked potential risk factors ranging from low to high. The 50-year TOT capture zone included eight of these PSOCs, with three being medium to high risk. A medium risk PSOC is attributed to the sanitary sewer lines located upgradient of the source water spring (MSL-3). High risk PSOCs include (1) old human waste leach fields and outdoor privies located on the hill above the source water spring (RMS-1) and (2) potential chemical spills along the State Highway 264 transportation corridor or dirt road immediately above the spring. Hand applied pesticides on the irrigated field next to the source water spring have also been reported; however, the use is considered limited.

Figure 8-3 also shows the delineated extent of two petroleum hydrocarbon contaminant plumes emanating from leaking underground storage tank sites, and an inorganic contaminant plume originating form the former Tuba City Landfill. These sites are outside but upgradient of the 50-year TOT groundwater capture zone of the source water spring and are the subject of ongoing characterization and remediation efforts. DBS&A (2000) identified additional PSOCs outside of the administrative protection zones defined for the most recent source water assessment activities.

8.2.4 Historical Water Quality

Historical water quality data were obtained from various sources for the PWS (Appendix D). Table 8-2 provides a summary of positive test results for the presence of bacteriological contamination, and any exceedance of established MCL values for regulated chemical and radiological contaminants. The Lower Moencopi PWS routinely exceeded the primary MCL for total coliform (131 sampling events since September 1997) until disinfection equipment was installed in November 2003. According to the EPA database, cadmium was detected at concentrations well above the primary MCL in 1998. The result is likely erroneous considering the extremely high reported value and non-detect for cadmium for a duplicated sample collected the same day.

Table 8-3 provides a summary of the EPA Safe Drinking Water Information System (SDWIS) listing of monitoring, reporting, and other violations for the PWS through 2004. All community PWS are required to monitor monthly for bacteria; annually for nitrate; every three years for volatile organic compounds (VOCs), synthetic organic compounds (SOCs), and inorganic compounds (IOCs); and every four years for radiological contaminants. Monitoring helps verify the effectiveness of source protection, preventative maintenance, and treatment measures. CCRs are intended to educate consumers who in turn are more likely to help protect drinking water sources. According to the EPA SDWIS, Lower Moencopi PWS has historically failed to meet regular monitoring requirements; however, in the last couple of years the PWS has achieved compliance, and is currently in compliance with monitoring and reporting requirements. The system was required to sample for IOCs, SOCs, and VOCs by December 31, 2005.

8.2.5 Source Water Susceptibility Analysis

Source water susceptibility determinations combine an evaluation of adjacent land use and hydrogeologic sensitivity to potential pollutants within delineated areas. Table 8-4 provides a score and cumulative risk

ED_005149_00040842-00084

ranking for the identified PSOCs. The scores provide an approximation of how serious a risk each potential contaminant poses to the drinking water supply, while the cumulative risk ranking developed for the Hopi SWAs provides a method to prioritize protection measures for the numerous wells supplying water across the reservation. The higher the number the more susceptible the drinking water source is to contamination. Source water susceptibility to contamination is considered low for risk ranking sums between 0 and 5; medium for sums between 16 and 30, and high for sums greater than 30.

The susceptibility analysis for the Lower Moencopi source water spring resulted in cumulative score of 46 (high risk). Key factors affecting susceptibility to groundwater contamination are as follows:

- Adjacent land use within the administrative protection zone consists of high population density areas. Within the 50-year TOT groundwater capture zone, land use consists of high density residential and irrigated agricultural activities.

- Wastewater systems serving the area are in close proximity and upgradient of the source water spring. The use of individual septic systems and outdoor privies immediately above the source water spring represent a high risk contaminant concern.

- Chemical contaminant concerns are considered moderate to high due to the proximity of the source water spring to transportation corridors. Accidental spills represent the greatest chemical contamination threat.

- Natural barriers that could retard the downward migration of contaminants are non-existent near the source water spring.

- Possible downward migration of contamination along the spring house foundation represents a significant threat.

- Naturally occurring inorganic contaminants are not a concern within the N-aquifer source water.

ED_005149_00040842-00085

9.0 SUMMARY AND RECOMMENDATIONS

The Hopi source water assessments were completed with the assistance of the Hopi Tribe WRP, HEPO, Facilities Management, BIA and IHS staff, PWS operators, and community administrative staff. A total of 16 public water systems supplied by 27 groundwater wells and 1-source water spring were field surveyed and assessed to identify susceptibility of each drinking water source to contamination.

Section 9.1 provides a summary of the source water assessment findings, and Section 9.2 a discussion of recommended source water protection measures that can be implemented to ensure that high quality drinking water is provided to reservation residents into the future.

9.1 SOURCE WATER ASSESSMENT SUMMARY

Table 9-1 provides a summary of the cumulative risk scores for each PWS evaluated. The numerical scoring system developed herein provides a "relativity rank" for the susceptibility of each drinking water source; the higher the score, the greater the risk of potential contamination. Prioritization of which potential contaminant sources to address in the protection phase of the SWAP program depends on Tribal priorities, resources, and input from the local community. As such, the intent of recommendations provided in Table 9-1 is to assist tribal planners with prioritizing future SWAP-related actions.

Systems with a "High" susceptibility rating are strongly encouraged to implement management controls within the source water assessment area to minimize the threat of these potential sources of contamination. Source water areas with a "Medium" susceptibility rating should consider implementing source measures that reduce the risk of potential contamination from sources closest to the well/intake. Systems with a "Low" susceptibility determination should initiate a public education and outreach program that focuses on protecting the drinking water resource and informing the public about activities that threaten the quality of the drinking water supply.

Most supply wells are in good shape and pose little risk of drinking water supply contamination. With the exception of the Moenkopi area, the PWSs are served by wells that are completed in confined aquifers that have overlying geologic layers of protection. Most of the wells with medium susceptibility determinations had a mix of residential, municipal, and commercial land use activities located in the area of delineation. As land use increases so does the potential for introduction of contaminants. Residential areas are the least likely to have contamination concerns, followed by municipal, commercial, and lastly industrial areas. Many wells (i.e., water supplies) are also affected by naturally occurring arsenic, fluoride, and total dissolved solids concentrations that increase the overall risk of providing marginal to poor quality water to the consumer. Locations close to highways also had a greater risk of contamination.

Through the establishment of conscientious maintenance practices, planning for the future, and ongoing public education activities, Tetra Tech believes that those responsible for the water system management can help to ensure a safe water supply for the public. Ensuring a safe water supply is critical for each community and for future generations.

ED_005149_00040842-00086

9.2 SOURCE WATER PROTECTION MEASURES

Protecting drinking water sources is a key element in protecting Hopi community and village health and well being. Several steps can be taken to assure the safety of the public water sources. Ongoing maintenance and monitoring of supply wells, strategic planning for future water needs, and public education are important tools for effective management control of the public resource. These activities are described in greater detail below.

<u>Maintenance and Monitoring Activities:</u>

- Ensure that groundwater quality monitoring is routinely conducted. Groundwater monitoring programs around pumping wells and high-risk potential sources of contamination can detect potential pollutants before they infiltrate the public water supply. Groundwater monitoring can ensure safe quality water is provided to the community.

- Cap and weld shut all abandoned water wells in the area of concern to eliminate access to well heads. Final disposition of out-of-service water wells should include proper abandonment by placement of a cement seal. In addition, all spring boxes, water hauling points, and livestock wells should be secured so that public access is controlled. Securing access to groundwater sources is an important tool in preventing contaminants from being introduced into public water supplies.

- Ensure all wash lines extend outside security fences surrounding the control building to prevent soil erosion under fence lines. Gaps underneath security fences can create unsafe conditions and jeopardize the public water supply.

- Install at a minimum three bumper guards (e.g., bollards) around each wellhead located outside the secured area. In addition to bumper guards, a locked chain link fence will provide added level of protection.

- Place 3' x 3' x 6" concrete slabs around each wellhead located outside of a pump house to improve sanitary protection around these wells. The concrete slab should slope away from the wellhead to drain precipitation and surface water.

- Monitor activities in areas of influence to ensure PSOCs are not being introduced.

<u>Planning Activities:</u>

- Review plans and help direct development within the community. Consider zoning ordinances to protect aquifers, recharge areas, and areas of influence. Limit or prevent high-risk development in these areas.

ED_005149_00040842-00087

- Implement health regulations to minimize risks to groundwater. Ensure that regulations exist that control the location, construction, and operation of septic tanks and leaching fields, and sanitary landfills in areas of influence.

- Restrict the storage and use of toxic and hazardous materials near well sites. Some communities prohibit the use of underground storage tanks in areas of influence around community wellheads. Other communities require periodic testing and replacement of USTs, permit requirements and corrosion protection for new tanks. In addition, some communities regulate limitations on herbicide and pesticide usage.

- Identify future problems and develop solutions. Analyze your community's "Development Plan" or "Master Plan." Identify land areas that have been identified for commercial and industrial use and that might prove to be trouble spots. Review plans for development of large municipal projects such as highways, hospitals, and utility expansions that could affect current and future well locations.

- Site new wells in low risk areas, where limited land uses with the potential to pollute exist. The capture zone models developed herein can be used to assist with future well siting.

- Develop a contingency plans for alternate water supplies in the event of contamination of primary water sources. If possible, develop a short-term emergency response plan and a long-term or permanent water supply alternative.

- Work with EPA on continuing basis to assess the impact of new rules for arsenic, groundwater disinfection, and alternative monitoring. The source water assessments may provide operational and monitoring flexibility under current or planned rules. The Tribe must have an EPA-approved SWAP to seek alternative monitoring requirements.

- Develop a plan to update the assessments in the SWAP as per EPA recommendation – the more comprehensive and current an assessment, the more likely they are to be useful in the future. The fully developed SWAP should therefore be viewed as a "living" document, to be updated, amended, and appended as Tribal water demands evolve.

- Continue development of the full SWP program. This assessment is a precursor to the development of a full SWP program to protect the drinking water area. Assessments provide the first of three steps in developing a full prevention program. EPA states that actions to complete a prevention program include: forming a team, monitoring source water quality, implementing management measures for sources of contamination, and contingency planning. This assessment is a tool for further efforts – not a complete process in and of itself.

ED_005149_00040842-00088

Public Education Activities:

- Attain administrative compliance. Each public water system is required to distribute consumer confidence reports (CCRs) to their customers on an annual basis that identify contaminants detected in its water and the attendant risks of exposure. Nationwide, the vast majority of violations are for systems that fail to monitor and report (i.e., administrative violations), rather than actual, significant violations of standards (i.e., MCL exceedances) – this holds true for the Hopi PWSs.

- Undertake public outreach through multi-media approach. Public support is important for the success of source water protection. The public should be informed regarding its role in protecting groundwater and surface water sources. This can be accomplished by public outreach, including (1) press releases to newspapers and radio stations, (2) newsletters, (3) brochures included with water bills, (4) public presentations at schools and community organizations, and (5) the development of slide shows and video tapes.

- Provide basic information on what groundwater is, the effects of groundwater contamination on public health, and the finite nature of groundwater across Tribal lands with an emphasis on encouraging preservation and conservation.

- Distribute information on how each businesses and individuals contribute to groundwater pollution.

- Provide information to the public on care of septic systems, and proper disposal of pesticides, solvents, used oil, and other contaminants.

- Consider working with community leaders on establishing a central location point where waste oil and other materials can be collected and recycled.

A summary of the each PWS source water assessment must be included in the consumer confidence report. Each PWS should provide information contained in this report as a brief summary of the results, i.e. the susceptibility of the system to contamination.

Hopi WRP will be conducting public meeting(s) on the consolidated report to receive final comments and input from the general public likely during the spring and summer of 2006 as public support is critical for source water protection program success. The maps produced by GIS are excellent educational tools that can be used to clearly show the public existing and potential risks to their drinking water source. Moreover, the capture zone analyses and projected aquifer drawdowns over time provide a graphical means to promote preservation and conservation of valuable groundwater resources on Tribal lands. Public meetings will encourage participation from the four main population centers across the reservation: First Mesa, Second Mesa, Third Mesa, and the Tuba City/Moenkopi area.

ED_005149_00040842-00089

At these meetings, materials from the source water assessment will be distributed and explained so that local residents can protect their drinking water.

ED_005149_00040842-00090

10.0 REFERENCES

Akers, J.P., and J.W. Harshbarger. 1958. Ground water in Black Mesa Basin and adjacent areas. U.S. Geological Survey, pp. 173-183. In New Mexico Geological Society, Ninth Field Conference.

Arizona Department of Environmental Quality (ADEQ), 1997. Wellhead Protection: A Guide for Arizona Communities. Prepared by Robert Wallin, Arizona Department of Environmental Quality, Water Quality Division, Tucson, Arizona.

———. 1999. Arizona Source Water Assessment Plan Final Draft

Brown, J.G., and J.H. Eychaner. 1988. Simulation of Five Ground-Water Withdrawal Projections for the Black Mesa Area, Navajo and Hopi Indian Reservations, Arizona. USGS, Water Resources Investigations Report 88-4000.

Cadmus, 2003 and 2004. Sanitary Survey Reports for Each Hopi PWS. Conducted for the U.S Environmental Protection Agency Region 9.

California DHS, January, 2000. Drinking Water Source Assessment and Protection (DWSAP) Program. Prepared by Division of Drinking Water and Environmental Management.

Cooley, M.E., J.W. Harshbarger, J.P. Akers, and W.F. Hardt. 1969. Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah. Geological Survey Professional Paper 521-A.

Eychaner, J.H, 1983. Geohydrology and effects of water use in the Black Mesa area, Navajo and Hopi Indian Reservations, Arizona, U.S. Geological Survey Water Supply Paper 2201

Environmental Protection Agency (EPA), 1993a. Seminar Publication, Wellhead Protection: A Guide for Small Communities. EPA/625/R-93/002. Office of Research and Development, Office of Water, Washington C 20460.

———, 1993b. Guidelines for Delineation of Wellhead Protection Areas. EPA-440/5-93-001. Office of Water.

———, 2000a. Drinking Water Quality in Indian Country: Protecting Your Sources. U.S. EPA Office of Water.

———, 2000b. 40 CFR 141 and 142 National Primary Drinking Water Regulations; Groundwater Rule; Proposed Rules.

———, 2004. Working with WhAEN 2000, Source Water Assessment for a Glacial Outwash Wellfield, Vincenner, Indiana. Office of Research and Development, U.S. EPA Washington DC 20460.

———, 2005. Preparing Your Drinking Water Consumer Confidence Report, Revised Guidance for Water Suppliers. EPA 816-R-05-002.

Daniel B. Stephens & Associates, Inc. (DBS&A), 1993a. Comprehensive Operations and Management Study for Hopi Public Water Supply Systems. Prepared for the Hopi Tribe, Kykotsmovi, Arizona.

ED_005149_00040842-00091

———, 1993b. Report of Year Two Activities, EPA 106 Water Quality Assessment Program, Volume I: Report Text. Prepared for the Hopi Tribe, Kykotsmovi, Arizona.

———, 1995. Hopi Tribe Water Quality Assessment Report, 1995 Section 305(b) Report. Prepared for The Hopi Tribe, Kykotsmovi, Arizona. September 30, 1995.

———, 1997. Hopi Tribe Nonpoint Source Assessment. Prepared for The Hopi Tribe, Kykotsmovi, Arizona.

———, 1998. Reports Related to Geophysical Evaluation of Village Supply Wells, Hopi Reservation.

———, 1999a. Hopi Watershed Protection and Restoration Guidelines. Prepared for The Hopi Tribe, Kykotsmovi, Arizona.

———, 2000a. Moenkopi Source Water Assessment and Protection. Prepared for the Hopi Tribe, Kykotsmovi, Arizona.

———, 2000b. Public Water System Feasibility Study, Shungopavi, Arizona. Prepared for Shungopavi Village Interim Board of Directors, Shungopavi, Arizona.

———, 2003. Village of Sipaulovi Water Supply Assessment. Prepared for Village of Sipaulovi, Sipaulovi, Arizona.

Harshbarger, J.W., Repenning, C.A., and Irwin, J.H., 1957. Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geological Survey Professional Paper 291, 74 p.

Hopi Tribe, 1996a. Wellhead Protection Manual. Prepared for the Hopi Tribe, Kykotsmovi, Arizona. Amended in 2001.

———, 1996b. The Hopi Tribe Standard Specification for Well Construction and Pump Installation. Prepared for the Hopi Tribe, Kykotsmovi, Arizona.

———, 1997a. Hopi Water Quality Standards. Prepared for The Hopi Tribe, Kykotsmovi, Arizona.

———, 1997b. Hopi Tribe Nonpoint Source Assessment. Prepared for The Hopi Tribe, Kykotsmovi, Arizona.

———, 2001a. Preliminary Hopi Wastewater Code. Prepared for The Hopi Tribe, Kykotsmovi, Arizona.

———, 2001b. Hopit Tunatya'at 2000: The Hopi Strategic Land Use and Development Plan. Prepared for The Hopi Tribal Council by the Office of Community Planning and Economic Development.

Indian Health Service (IHS), 1991. Project Summary, Tribal Utility Authority Hopi Indian Reservation Navajo and Coconino Counties, Arizona. Public Law 86-121, HIS Project Number PH 91-715. U.S. Department of Health and Human Services Public Health Service, Indian Health Service, Phoenix Area Office June 1991.

———, 2005. Email communication from Erica Schoen (IHS) to Joelynn Roberson (Hopi WRP) regarding current population served by the Polacca public water system.

ED_005149_00040842-00092

Griffith, Stacy R. 1993. Geochemistry and reaction path modeling of the N-aquifer system, Hopi Indian Reservation, northeastern Arizona. M.S. thesis, Northern Arizona University, Geology Department, 107p.

Northern Arizona University. 1992. Final Report of Year One Activities Associated with the Hopi Water Quality Assessment Project. Prepared for the Hopi Tribe.

Lopes, Thomas J., and Hoffman, John P., 1997. Geochemical Analyses of Ground-Water Ages, Recharge Rates, and Hydraulic Conductivity of the N-Aquifer, Black Mesa Area, Arizona. U.S. Geological Survey Water Resources Investigation Report 96-4190.

McDonald, M.G. and A.W. Harbaugh, 1988. A modular three-dimensional finite difference groundwater flow model in techniques of water-resource investigations of the U.S. Geological Survey, Book 6, Chapter A1: U.S. Geological Survey.

New Mexico Environment Department (NMED), 2000. State of New Mexico Source Water Assessment and Protection Program. Prepared by the Drinking Water Bureau Field Operations Division, New Mexico Environment Department.

Plateau Engineering, 2002. Water Supply and Water System Evaluation and Recommendations, New Second Mesa Day School.

———, 2005. Water Supply and Water System Evaluation and Recommendations, New Second Mesa Day School – Existing School Site.

Pollack, D.W., 1989. Documentation of computer programs to compute and display pathlines using results from the U.S. Geological Survey modular three-dimensional finite-difference groundwater flow model: U.S Geological Survey Open File Report 89-381.

Tetra Tech EMI, 2004. C-Aquifer Exploratory Drilling Program near the Villages of Moenkopi, Arizona. Prepared for the Hopi Tribe Water Resources Program.

———, 2005. Shungopavi Water Supply Analysis. Prepared for the Hopi Tribe Water Resources Program, October 10, 2005.

Totten, Glen, 2000. Protecting Drinking Water: A Workbook for Tribes. Prepared by the Water Education Foundation. Funded by the U.S, Environmental Protection Agency.

Truini, Margot, and Longsworth, Steve A, 2003. Hydrogeology of the D Aquifer and Movement and Ages of Ground Water Determined from Geochemical and Isotopic Analyses, Black Mesa Area, Northeastern Arizona. U.S. Geological Survey Water Resources Investigation Report 03-4189.

Truini, Margot, J.P. Macy, and T.J Porter, 2005. Ground-Water, Surface-Water, and Water-Chemistry Data, Black Mesa Area, Northeastern Arizona, 2003-04. U.S. Geological Survey Open-Fie Report 2005-1080.

Wickham, M. 1992. The geochemistry of surface water and groundwater interactions for selected Black Mesa drainages, Little Colorado River Basin, Arizona. M.S. Thesis, University of Arizona, Tucson, Arizona.

ED_005149_00040842-00093